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EPA Office of Compliance Sector Notebook Project:

Profile of the Metal Casting Industry

February 1998

Office of Compliance
Office of Enforcement and Compliance Assurance
U.S. Environmental Protection Agency
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Electronic versions of all Sector Notebooks are available via Internet on the Enviroene World Wide Web. Downloading procedures are described in Appendix A of this document.

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AFS -	AIRS Facility Subsystem (CAA database)
AFS-	American Foundrymen's Society
AIRS -	Aerometric Information Retrieval System (CAA database)
BIFs -	Boilers and Industrial Furnaces (RCRA)
BOD -	Biochemical Oxygen Demand
CAA -	Clean Air Act
CAAA -	Clean Air Act Amendments of 1990
CERCLA -	Comprehensive Environmental Response, Compensation and Liability Act
CERCLIS -	CERCLA Information System
CFCs -	Chlorofluorocarbons
CO -	Carbon Monoxide
COD -	Chemical Oxygen Demand
CSI -	Common Sense Initiative
CWA -	Clean Water Act
D&B -	Dun and Bradstreet Marketing Index
ELP -	Environmental Leadership Program
EPA -	United States Environmental Protection Agency
EPCRA -	Emergency Planning and Community Right-to-Know Act
FIFRA -	Federal Insecticide, Fungicide, and Rodenticide Act
FINDS -	Facility Indexing System
HAPs -	Hazardous Air Pollutants (CAA)
HSDB -	Hazardous Substances Data Bank
IDEA -	Integrated Data for Enforcement Analysis
LDR -	Land Disposal Restrictions (RCRA)
LEPCs -	Local Emergency Planning Committees
MACT -	Maximum Achievable Control Technology (CAA)
MCLGs -	Maximum Contaminant Level Goals
MCLs -	Maximum Contaminant Levels
MEK -	Methyl Ethyl Ketone
MSDSs -	Material Safety Data Sheets
NAAQS -	National Ambient Air Quality Standards (CAA)
NAFTA -	North American Free Trade Agreement
NCDB -	National Compliance Database (for TSCA, FIFRA, EPCRA)
NCP -	National Oil and Hazardous Substances Pollution Contingency Plan
NEIC -	National Enforcement Investigation Center
NESHAP -	National Emission Standards for Hazardous Air Pollutants
NO_2 -	Nitrogen Dioxide
NOV -	Notice of Violation
NO_X -	Nitrogen Oxide
NPDES -	National Pollution Discharge Elimination System (CWA)
NPL -	National Priorities List
NRC -	National Response Center
NSPS -	New Source Performance Standards (CAA)

OAR -   Office of Air and Radiation
OECA -   Office of Enforcement and Compliance Assurance
OPA -   Oil Pollution Act
OPPTS -   Office of Prevention, Pesticides, and Toxic Substances
OSHA -   Occupational Safety and Health Administration
OSW -   Office of Solid Waste
OSWER -   Office of Solid Waste and Emergency Response
OW -   Office of Water
P2 -   Pollution Prevention
PCS -   Permit Compliance System (CWA Database)
POTW -   Publicly Owned Treatments Works
RCRA -   Resource Conservation and Recovery Act
RCRIS -   RCRA Information System
SARA -   Superfund Amendments and Reauthorization Act
SDWA -   Safe Drinking Water Act
SEPs -   Supplementary Environmental Projects
SERCs -   State Emergency Response Commissions
SIC -   Standard Industrial Classification
SO_2 -   Sulfur Dioxide
SO_X -   Sulfur Oxides
TOC -   Total Organic Carbon
TRI -   Toxic Release Inventory
TRIS -   Toxic Release Inventory System
TCRIS -   Toxic Chemical Release Inventory System
TSCA -   Toxic Substances Control Act
TSS -   Total Suspended Solids
UIC -   Underground Injection Control (SDWA)
UST -   Underground Storage Tanks (RCRA)
VOCs -   Volatile Organic Compounds

<div align="center">

METAL CASTING INDUSTRY
(SIC 332 AND 336)

</div>

I. INTRODUCTION TO THE SECTOR NOTEBOOK PROJECT

I.A. Summary of the Sector Notebook Project

Integrated environmental policies based upon comprehensive analysis of air, water and land pollution are a logical supplement to traditional single-media approaches to environmental protection. Environmental regulatory agencies are beginning to embrace comprehensive, multi-statute solutions to facility permitting, enforcement and compliance assurance, education/ outreach, research, and regulatory development issues. The central concepts driving the new policy direction are that pollutant releases to each environmental medium (air, water and land) affect each other, and that environmental strategies must actively identify and address these inter-relationships by designing policies for the "whole" facility. One way to achieve a whole facility focus is to design environmental policies for similar industrial facilities. By doing so, environmental concerns that are common to the manufacturing of similar products can be addressed in a comprehensive manner. Recognition of the need to develop the industrial "sector-based" approach within the EPA Office of Compliance led to the creation of this document.

The Sector Notebook Project was originally initiated by the Office of Compliance within the Office of Enforcement and Compliance Assurance (OECA) to provide its staff and managers with summary information for eighteen specific industrial sectors. As other EPA offices, states, the regulated community, environmental groups, and the public became interested in this project, the scope of the original project was expanded to its current form. The ability to design comprehensive, common sense environmental protection measures for specific industries is dependent on knowledge of several inter-related topics. For the purposes of this project, the key elements chosen for inclusion are: general industry information (economic and geographic); a description of industrial processes; pollution outputs; pollution prevention opportunities; Federal statutory and regulatory framework; compliance history; and a description of partnerships that have been formed between regulatory agencies, the regulated community and the public.

For any given industry, each topic listed above could alone be the subject of a lengthy volume. However, in order to produce a manageable document, this project focuses on providing summary information for each topic. This format provides the reader with a synopsis of each issue, and references where more in-depth information is available. Text within each profile was researched from a variety of sources, and was usually condensed from more detailed sources pertaining to specific topics. This approach allows for a wide coverage of activities that can be further explored based upon the citations

and references listed at the end of this profile. As a check on the information included, each notebook went through an external review process. The Office of Compliance appreciates the efforts of all those that participated in this process and enabled us to develop more complete, accurate and up-to-date summaries. Many of those who reviewed this notebook are listed as contacts in Section IX and may be sources of additional information. The individuals and groups on this list do not necessarily concur with all statements within this notebook.

I.B. Additional Information

Providing Comments

OECA's Office of Compliance plans to periodically review and update the notebooks and will make these updates available both in hard copy and electronically. If you have any comments on the existing notebook, or if you would like to provide additional information, please send a hard copy and computer disk to the EPA Office of Compliance, Sector Notebook Project, 401 M St., SW (2223-A), Washington, DC 20460. Comments can also be uploaded to the Enviroene World Wide Web for general access to all users of the system. Follow instructions in Appendix A for accessing this system. Once you have logged in, procedures for uploading text are available from the on-line Enviroene Help System.

Adapting Notebooks to Particular Needs

The scope of the industry sector described in this notebook approximates the national occurrence of facility types within the sector. In many instances, industries within specific geographic regions or states may have unique characteristics that are not fully captured in these profiles. The Office of Compliance encourages state and local environmental agencies and other groups to supplement or re-package the information included in this notebook to include more specific industrial and regulatory information that may be available. Additionally, interested states may want to supplement the "Summary of Applicable Federal Statutes and Regulations" section with state and local requirements. Compliance or technical assistance providers may also want to develop the "Pollution Prevention" section in more detail. Please contact the appropriate specialist listed on the opening page of this notebook if your office is interested in assisting us in the further development of the information or policies addressed within this volume. If you are interested in assisting in the development of new notebooks for sectors not already covered, please contact the Office of Compliance at 202-564-2395.

II. INTRODUCTION TO THE METAL CASTING INDUSTRY

This section provides background information on the size, geographic distribution, employment, production, sales, and economic condition of the metal casting industry. Facilities described within this document are described in terms of their Standard Industrial Classification (SIC) codes.

II.A. Introduction, Background, and Scope of the Notebook

The metal casting industry makes parts from molten metal according to an end-user's specifications. Facilities are typically categorized as casting either ferrous or nonferrous products. The metal casting industry described in this notebook is categorized by the Office of Management and Budget (OMB) under Standard Industrial Classification (SIC) codes 332 Iron and Steel Foundries and 336 Nonferrous Foundries (Castings). The die casting industry is contained within the SIC 336 category since die casting establishments primarily cast nonferrous metals. OMB is in the process of changing the SIC code system to a system based on similar production processes called the North American Industrial Classification System (NAICS). (In the NAIC system, iron and steel foundries, nonferrous foundries, and die casters are all classified as NAIC 3315.)

Although both foundries and die casters are included in this notebook, there are significant differences in the industrial processes, products, facility size and environmental impacts between die casters and foundries. Die casting operations, therefore, are often considered separately throughout this notebook.

In addition to metal casting, some foundries and die casters carry out further operations on their cast parts that are not the primary focus of this notebook. Examples include heat treating (e.g. annealing), case hardening, quenching, descaling, cleaning, painting, masking, and plating. Such operations can contribute significantly to a facility's total waste generation. Typical wastes generated during such operations include spent cyanide baths, salt baths, quenchents, abrasive media, solvents and plating wastes. For more information on these processes, refer to the Fabricated Metal Products Industry Sector Notebook.

II.B. Characterization of the Metal Casting Industry

Foundries and die casters that produce ferrous and nonferrous castings generally operate on a job or order basis, manufacturing castings for sale to others companies. Some foundries, termed captive foundries, produce castings as a subdivision of a corporation that uses the castings to produce larger products such as machinery, motor vehicles, appliances or plumbing fixtures.

In addition, many facilities do further work on castings such as machining, assembling, and coating.

II.B.1. Product Characterization

About 13 million tons of castings are produced every year in the U.S. (U.S. DOE, 1996). Most of these castings are produced from recycled metals. There are thousands of cast metal products, many of which are incorporated into other products. Almost 90 percent of all manufactured products contain one or more metal castings (LaRue, 1989). It is estimated that on average, every home contains over a ton of castings in the form of pipe fittings, plumbing fixtures, hardware, and furnace and air conditioner parts. Automobiles and other transportation equipment use 50 to 60 percent of all castings produced - in engine blocks, crankshafts, camshafts, cylinder heads, brake drums or calipers, transmission housings, differential casings, U-joints, suspension parts, flywheels, engine mount brackets, front-wheel steering knuckles, hubs, ship propellers, hydraulic valves, locomotive undercarriages, and railroad car wheels. The defense industry also uses a large portion of the castings produced in the U.S. Typical cast parts used by the military include tank tracks and turrets and the tail structure of the F-16 fighter (Walden, 1995). Some of other common castings include: pipes and pipe fittings, valves, pumps, pressure tanks, manhole covers, and cooking utensils. Figure 1 shows the proportion of various types of castings produced in the U.S.

Figure 1: Uses of Cast Metal Products
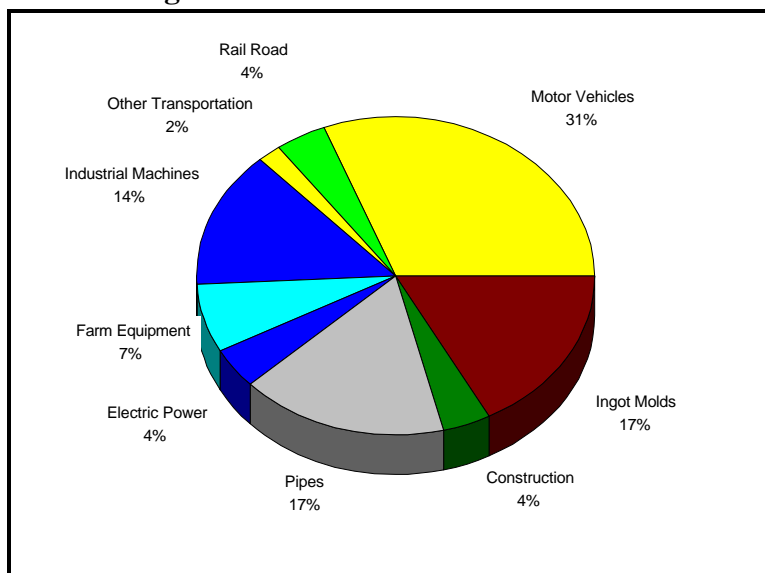
Source: U.S. Department of Energy, 1996.

Iron and Steel (Ferrous) Castings

Depending on the desired properties of the product, castings can be formed from many types of metals and metal alloys. Iron and steel (ferrous) castings are categorized by four-digit SIC code by the Bureau of Census according to the type of iron or steel as follows:

SIC 3321 - Gray and Ductile Iron Foundries
SIC 3322 - Malleable Iron Foundries
SIC 3324 - Steel Investment Foundries
SIC 3325 - Steel Foundries, Not Elsewhere Classified

Gray and Ductile Iron make up almost 75 percent of all castings (ferrous and nonferrous) by weight (see Figure 2). Gray iron contains a higher percentage of carbon in the form of flake graphite and has a lower ductility than other types of iron. It is used extensively in the agricultural, heavy equipment, engine, pump, and power transmission industries. Ductile iron has magnesium or cerium added to change the form of the graphite from flake to nodular. This results in increased ductility, stiffness, and tensile strength (Loper, 1985).

Figure 2: Types of Metals Cast
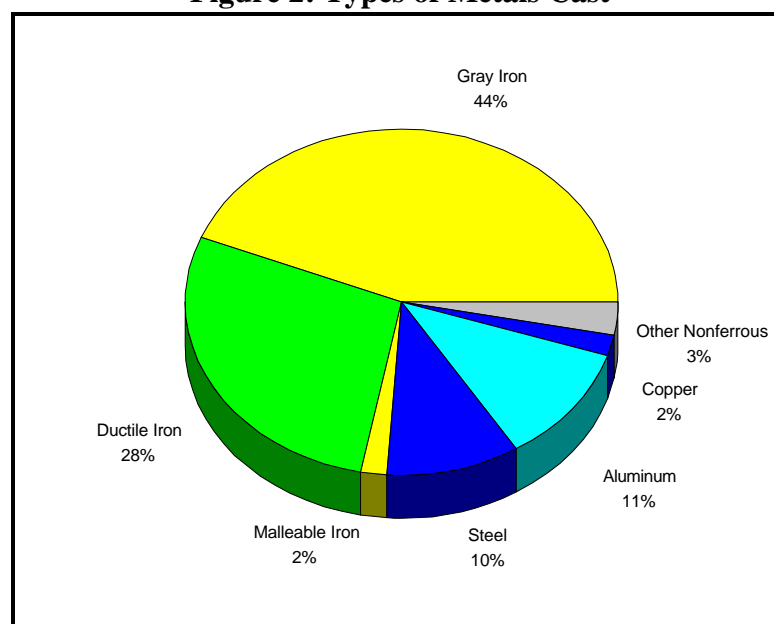
Source: U.S. Department of Energy, 1996.

Malleable iron foundries produce only about two percent of all castings (ferrous and nonferrous). Malleable iron contains small amounts of carbon, silicon, manganese, phosphorus, sulfur and metal alloys to increase strength and endurance. Malleable iron has excellent machinability and a high

resistance to atmospheric corrosion. It is often used in the electrical power, conveyor and handling equipment, and railroad industries.

Compared to steel, gray, ductile, and malleable iron are all relatively inexpensive to produce, easy to machine, and are widely used where the superior mechanical properties of steel are not required (Loper, 1985).

Steel castings make up about 10 percent of all castings (ferrous and nonferrous). In general, steel castings have better strength, ductility, heat resistance, durability and weldability than iron castings. There are a number of different classes of steel castings based on the carbon or alloy content, with different mechanical properties. A large number of different alloying metals can be added to steel to increase its strength, heat resistance, or corrosion resistance (Loper, 1985). The steel investment casting method produces high-precision castings, usually smaller castings. Examples of steel investment castings range from machine tools and dies to golf club heads.

Nonferrous Castings

Nonferrous castings are categorized by four-digit SIC code by the Bureau of Census according to the type of metal as follows:

SIC 3363 - Aluminum Die-Castings
SIC 3364 - Nonferrous Die-Castings, Except Aluminum
SIC 3365 - Aluminum Foundries
SIC 3366 - Copper Foundries
SIC 3369 - Nonferrous Foundries, Except Aluminum and Copper

Nonferrous foundries often use the same basic molding and casting techniques as ferrous foundries. Many foundries cast both ferrous and nonferrous metals. Aluminum, copper, zinc, lead, tin, nickel, magnesium and titanium are the nonferrous metals of primary commercial importance. Usually, these metals are cast in combinations with each other or with some of about 40 other elements to make many different nonferrous alloys. A few of the more common nonferrous alloys are: brass, bronze, nickel-copper alloys (Monel), nickel-chromium-iron alloys, aluminum-copper alloys, aluminum-silicon alloys, aluminum-magnesium alloys, and titanium alloys.

Nonferrous metals are used in castings that require specific mechanical properties, machinability, and/or corrosion resistance (Kunsman, 1985). Aluminum and aluminum alloy castings are produced in the largest volumes; 11 percent of all castings (ferrous and nonferrous) by weight are aluminum. Copper and copper alloy castings make up about two percent of all castings by weight (DOE, 1996). Figure 2 shows the proportions of raw material types used in castings in the U.S.

About 9 percent by weight of all cast metal products are produced using die casting techniques (DOE, 1996). Die casting is cost effective for producing large numbers of a casting and can achieve a wide variety of sizes and shapes with a high degree of accuracy. Holes, threads, and gears can be cast, reducing the amount of metal to be machined from the casting. Most die castings are aluminum; however, lead, tin, zinc, copper, nickel, magnesium, titanium, and beryllium alloys are also die cast. Die casts are usually limited to nonferrous metals and are often under ten pounds. A wide variety of products are produced using the die casting process, ranging from tiny wrist watch parts to one-piece automobile engine blocks (Street, 1977). Other typical die castings include: aluminum transmission cases, bearings, bushings, valves, aircraft parts, tableware, jewelry and household appliance parts.

II.B.2. Industry Size and Geographic Distribution

According to the *1992 Census of Manufacturers* data, there are approximately 2,813 metal casting facilities under SIC codes 332 and 336. The payroll for 1992 totaled $5.7 billion for a workforce of 158,000 employees, and value of shipments totaled $18.8 billion. The industry's own estimates of the number of facilities and employment are somewhat higher at 3,100 facilities employing 250,000 in 1994 (Cast Metals Coalition, 1995). Based on the Census of Manufacturers data, the industry is labor intensive. The value of shipments per employee, a measure of labor intensity, is $119,000 that is less than half of the steel manufacturing industry value ($245,000 per employee) and less than seven percent of the petroleum refining industry value ($1.8 million per employee).

Most metal casting facilities in the U.S. are small. About seventy percent of the facilities employ fewer than 50 people (see Table 1). Most metal casting facilities manufacture castings for sale to other companies (U.S. Census of Manufacturers, 1992). An important exception are the relatively few (but large) "captive" foundries operated by large original equipment manufacturers (OEM's) including General Motors, Ford, Chrysler, John Deere, and Caterpillar. OEM's account for a large portion of the castings produced and employ a significant number of the industry's workforce.

Although die casting establishments account for only about 9 percent of cast products by weight, they make up about 20 percent of metal casting establishments and value of sales (U.S. Census of Manufacturers, 1992). In proportion to the industry size, there is very little difference between the size distribution of foundries and die casters.

Table 1: Facility Size Distribution for the Metal Casting Industry				
Employees per Facility	**Ferrous and Nonferrous Foundries (SIC 332, 3365, 3366, and 3369)**		**Die Casting Establishments (SIC 3363 and 3364)**	
	Number of Facilities	Percentage of Facilities	Number of Facilities	Percentage of Facilities
1-9	742	33%	167	28%
10-49	843	38%	214	36%
50-249	494	22%	186	31%
250-499	90	4%	25	4%
500-2499	43	2%	4	1%
2500 or more	4	0%	0	0%
Total	2216	100%	596	100%
Source: U.S. Department of Commerce, Census of Manufacturers, 1992.				

Geographic Distribution

The geographic distribution of the metal casting industry resembles that of the iron and steel industry. The highest geographic concentration of facilities is in the Great Lakes, midwest, southeast regions and California. The top states by number of facilities in order are: California, Ohio, Pennsylvania, Michigan, Illinois, Wisconsin, and Indiana. Figure 3 shows the U.S. distribution of facilities based on 1992 data from the U.S. Census of Manufacturers. Historically, locations for metal casting establishments were selected for their proximity to raw materials (iron, steel, and other metals), coal, and water for cooling, processing, and transportation. Traditional metal casting regions included the Monongahela River valley near Pittsburgh and along the Mahoning River near Youngstown, Ohio. The geographic concentration of the industry is changing as facilities are built where scrap metal and electricity are available at a reasonable cost and there is a local market for the cast products.

Figure 3: Geographic Distribution of Metal Casting Establishments
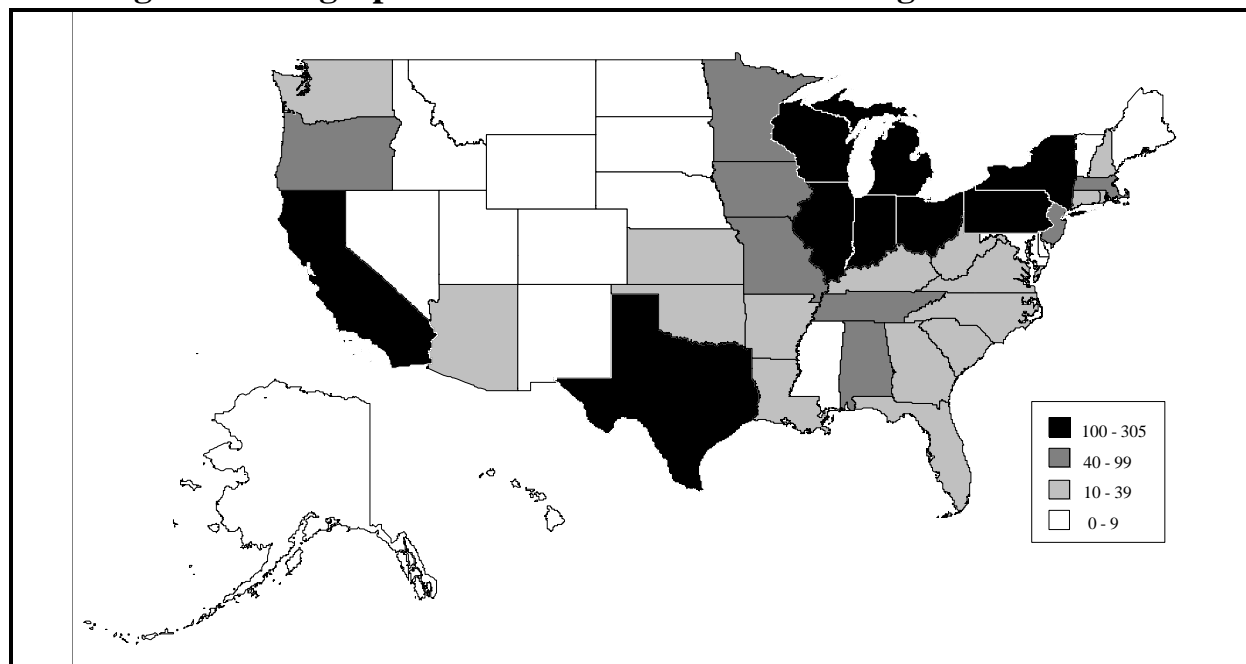
Source: U.S. Census of Manufacturers, 1992.

Dun & Bradstreet's *Million Dollar Directory,* compiles financial data on U.S. companies including those operating within the metal casting industry. Dun & Bradstreet ranks U.S. companies, whether they are a parent company, subsidiary or division, by sales volume within their assigned 4-digit SIC code. Readers should note that: (1) companies are assigned a 4-digit SIC that resembles their principal industry most closely; and (2) sales figures include total company sales, including subsidiaries and operations (possibly not related to metal casting). Additional sources of company specific financial information include Standard & Poor's *Stock Report Services*, *Ward's Business Directory of U.S. Private and Public Companies*, Moody's Manuals, and annual reports.

Table 2: Top U.S. Metal Casting Companies		
Rank[a]	**Company[b]**	**1995 Sales (millions of dollars)**
1	Howmet Corporation - Greenwich, CT	900
2	Newell Operating Co. - Freeport, IL	796
3	CMI International Inc. - Southfield, MI	561
4	Precision Castparts Corporation - Portland, OR	557
5	Grede Foundries - Milwaukee, WI	460
6	United States Pipe and Foundry - Birmingham, AL	412
7	George Koch Sons, Inc.	390
8	Varlen Corporation - Naperville, IL	387
9	Allied Signal, Inc.	260
10	North American Royalties, Inc.	254

Note: [a]Not all sales can be attributed to the companies' metal casting operations.

[b] Companies shown listed SIC 332, 3363, 3364, 3365, 3369. Many large companies operating captive metal casting facilities produce other goods and are not shown here.

Source: *Dunn & Bradstreet's Million Dollar Directory - 1996.*

II.B.3. Economic Trends

The U.S. metal casting industry experienced an unprecedented drop in production during the 1970's and 1980's. Production of cast metal products declined from 19.6 million tons in 1972 to 11.3 million tons in 1990. During this period over 1,000 metal casting facilities closed (DOE, 1996). A number of reasons have been given for this decline including: decreased U.S. demand for cast metal resulting from decreases in automobile production and smaller, lighter weight vehicles for increased fuel efficiency; increased foreign competition; increased use of substitute materials such as plastics, ceramics, and composites; and increased costs to comply with new environmental and health and safety regulations.

The metal casting industry began to recover in the early 1990's; however, it still produces less than in the early 1970's. The recovery has been attributed to increases in domestic demand in part due to increases in automobile production. In addition, exports of castings have increased and imports have decreased. Between 1993 and 1994 alone the U.S. increased its share of world metal casting production from 18 percent to 20 percent. The increases in production came primarily from increases in capacity utilization at existing

facilities rather than an increase in facilities. In fact, the American Foundrymen's Society estimates that the number of metal casting facilities decreased by over 200 between 1990 and 1994 (DOE, 1996).

In 1972, only five percent of all castings were aluminum. Today aluminum accounts for over 11 percent of the market (DOE, 1996). Aluminum castings are steadily comprising a larger share of the castings market as their use in motor vehicle and engine applications continues to grow. To produce lighter weight, more fuel efficient vehicles, the automobile industry is in the process redesigning the engine blocks, heads and other parts of passenger cars and light trucks for aluminum. Cast aluminum is expected to increase from 140 pounds per vehicle in 1995 to 180 pounds per vehicle in 2004. This is primarily at the expense of gray iron which will decrease from 358 pounds per vehicle in 1995 to 215 pounds in 2004 (*Modern Casting*, September, 1995).

The U.S. metal casting industry that emerged from the two decades of decline in the 1970's and 1980's is stronger and more competitive. The industry is developing new markets and recapturing old markets. Research and development has resulted in technological advances that have improved product quality, overall productivity and energy efficiency. Important recent technological advances have included Computer Aided Design (CAD) of molds and castings, the use of sensors and computers to regulate critical parameters within the processes, and the use of programmable robots to perform dangerous, time consuming or repetitive tasks.

To stay competative, the industry has identified the following priority areas for research and development to improve its processes and products:

• improving casting technologies
• developing new casting materials (alloys) and die materials
• developing higher strength and lower weight castings
• improving process controls
• improving dimensional control
• improving the quality of casting material
• reducing casting defects (DOE, March 1996)
• developing environmentally improved materials to meet today's regulations (AFS, 1997)

Research into new casting methods and improvements in the current methods are resulting in improved casting quality, process efficiency, and environmental benefits.

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III. INDUSTRIAL PROCESS DESCRIPTION

This section describes the major industrial processes within the metal casting industry, including the materials and equipment used and the processes employed. The section is designed for those interested in gaining a general understanding of the industry, and for those interested in the inter-relationship between the industrial process and the topics described in subsequent sections of this profile -- pollutant outputs, pollution prevention opportunities, and Federal regulations. This section does not attempt to replicate published engineering information that is available for this industry. Refer to Section IX for a list of resource materials and contacts that are available.

This section specifically contains a description of commonly used production processes, associated raw materials, the by-products produced or released, and the materials either recycled or transferred off-site. This discussion, coupled with schematic drawings of the identified processes, provide a concise description of where wastes may be produced in the process. This section also describes the potential fate (via air, water, and soil pathways) of these waste products.

III.A. Industrial Processes in the Metal Casting Industry

Many different metal casting techniques are in use today. They all have in common the construction of a mold with a cavity in the external shape of the desired cast part followed by the introduction of molten metal into the mold.

For the purposes of this profile, the metal casting process has been divided into the following five major operations:

- Pattern Making
- Mold and Core Preparation and Pouring
- Furnace Charge Preparation and Metal Melting
- Shakeout, Cooling and Sand Handling
- Quenching, Finishing, Cleaning and Coating

All five operations may not apply to each casting method. Since the major variations between processes occur in the different types of molds used, Section III.A.2 - Mold and Core Preparation is divided into subsections describing the major casting processes. In addition to the casting techniques described below, there are numerous special processes and variations of those processes that cannot be discussed here. Nevertheless, such processes may play an important role in a facility's efforts to comply with environmental requirements. Refer to Section IX for a list of references providing more detail on casting processes.

Note that die casting operations have been presented separately in Section III.A.6. The different processes, equipment, and environmental impacts of die casting do not fit easily into operations outlined above.

III.A.1. Pattern Making

Pattern making, or foundry tooling, requires a high level of skill to achieve the close tolerances required of the patterns and coreboxes. This step is critical in the casting process since the castings produced can be no better than the patterns used to make them. In some pattern making shops, computer-aided drafting (CAD) is used in the design of patterns. Cutter tool paths are designed with computer-aided manufacturing (CAM). Numerical output from these computers is conveyed to computer-numerical-controlled (CNC) machine tools, which then cut the production patterns to shape. Such computer-aided systems have better dimensional accuracy and consistency than hand methods (LaRue, 1989).

Patterns and corebox materials are typically metal, plastic, wood or plaster. Wax and polystyrene are used in the investment and lost foam casting processes, respectively. Pattern makers have a wide range of tools available including wood working and metal machining tools. Mechanical connectors and glues are used to join pattern pieces. Wax, plastic or polyester putty are used as "fillet" to fill or round the inside of square corners (LaRue, 1989).

Wastes Generated
Very little waste is generated during pattern making compared to other foundry operations. Typical pattern shop wastes include scrap pattern materials (wood, plastics, metals, waxes, adhesives, etc.) and particulate emissions from cutting, grinding and sanding operations. Waste solvents and cleaners may be generated from equipment cleaning.

Table 3: Comparison of Several Casting Methods (approximate and depending upon the metal)					
	Green Sand Casting	**Permanent Mold Cast**	**Die Casting**	**Sand-Shell CO_2-Core Casting**	**Investment Casting**
Relative cost in quantity	low	low	lowest	medium high	highest
Relative cost for small number	lowest	high	highest	medium high	medium
Permissible weight of casting	up to about 1 ton	100 lbs.	60 lbs.	Shell: ozs. - 250 lbs. CO_2: 1/2 lbs. - tons	Ozs. - 100 lbs.
Thinnest section castable, inches	1/10	1/8	1/32	1/10	1/16
Typical dimensional tolerance, inches (not including parting lines)	.012	0.03	0.01	.010	0.01
Relative surface finish	fair to good	good	best	Shell: good CO_2: fair	very good
Relative mechanical properties	good	good	very good	good	fair
Relative ease of casting complex design	fair to good	fair	good	good	best
Relative ease of changing design in production	best	poor	poorest	fair	fair
Range of alloys that can be cast	unlimited	copper base and lower melting point metals preferable	aluminum base and lower melting preferable	unlimited	limited

Source: American Foundrymen's Society, 1981.

III.A.2. Mold and Core Preparation and Pouring

The various processes used to cast metals are largely defined by the procedures and materials used to make the molds and cores. Table 3 summarizes the major casting methods and their applications. A mold and cores (if required) are usually made for each casting. These molds and cores

are destroyed and separated from the casting during shakeout (see Section III.A.4 - Shakeout, Cooling and Sand Handling). (Exceptions include the permanent mold process and die casting process in which the molds are used over and over again.) Most sand is reused over and over in other molds; however, a portion of sand becomes spent after a number of uses and must be removed as waste. Mold and core making are, therefore, a large source of foundry wastes.

Sand Molds and Cores

For most sand casting techniques, the following summary of the process applies (see Figure 4). First, engineers design the casting and specify the metal or alloy to be cast. Next, a pattern (replica of the finished piece) is constructed from either plastic, wood, metal, plaster or wax. Usually, the pattern is comprised of two halves. The molding sand is shaped around the pattern halves in a metal box (flask) and then removed, leaving the two mold halves. The top half of the mold (the cope) is assembled with the bottom half (the drag) which sits on a molding board. The interface between the two mold halves is called a parting line. Weights may be places on the cope to help secure the two halves together. The molten metal is poured or injected into a hole in the cope called a sprue or sprue basin which is connected to the mold cavity by runners. The runners, sprue, gates, and risers comprise the mold's gating system, which is designed to carry molten metal smoothly to all parts of the mold. The metal is then allowed to solidify within the space defined by the mold.

Since the molds themselves only replicate the external shape of the pattern, cores are placed inside the mold to form any internal cavities. Cores are produced in a core box, which is essentially a permanent mold that is developed in conjunction with the pattern. So that molten metal can flow around all sides of the cores, they are supported on core prints (specific locations shaved into the mold) or on by metal supports called chaplets.

Foundry molds and cores are most commonly constructed of sand grains bonded together to form the desired shape of the casting. Sand is used because it is inexpensive, is capable of holding detail, and resists deformation when heated. Sand casting affords a great variety of casting sizes and complexities. Sand also offers the advantage of reuse of a large portion of the sand in future molds. Depending on the quantity of castings, however, the process can be slower and require more man-hours than processes not requiring a separate mold for each casting. In addition, castings from sand molds are dimensionally less accurate than those produced from some other techniques and often require a certain amount of machining (USITC, 1984). The pattern making, melting, cleaning, and finishing operations are essentially the same whether or not sand molds are used. Sand molds and cores will,

however, require the additional operational steps involved with handling quantities of used mold and core sand (see Section III.A.5 - Sand Handling).

In general, the various binding systems can be classified as either clay bonded sand (green sand) or chemically bonded sand. The type of binding system used depends on a number of production variables, including the temperature of the molten metal, the casting size, the types of sand used, and the alloys to be cast. The differences in binding systems can have an impact on the amounts and toxicity of wastes generated and potential releases to the environment.

Figure 4: Sand Mold and Core Cross Section
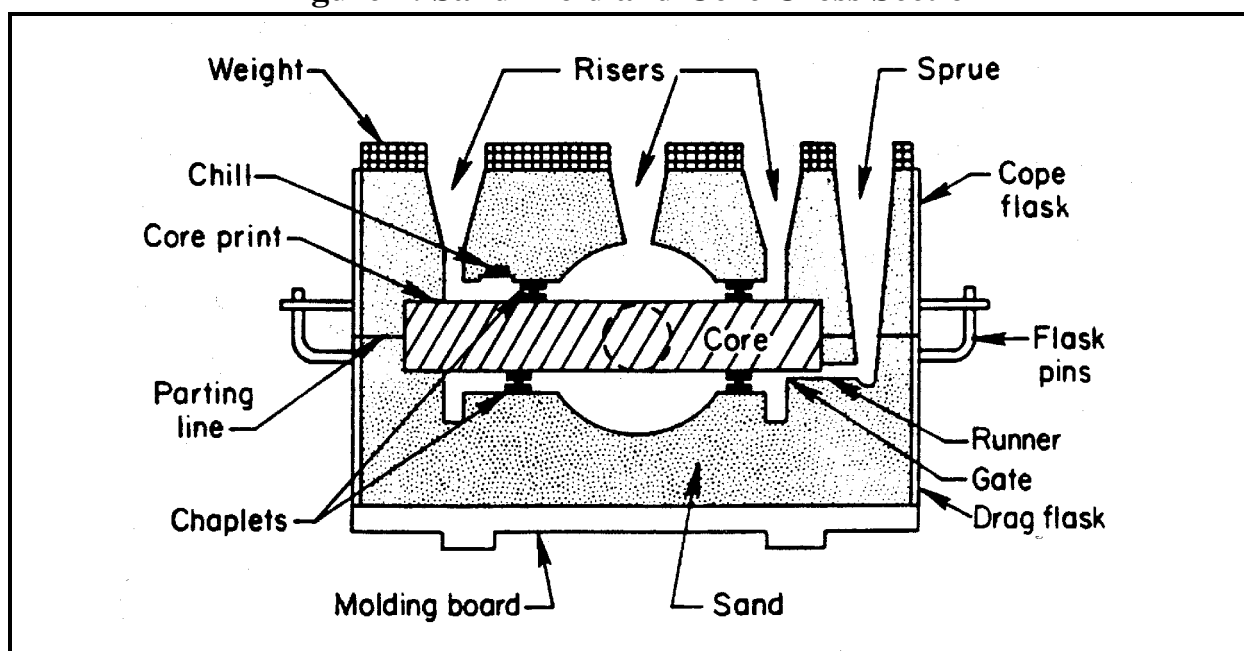
Source: American Foundrymen's Society, 1981.

Some sand molding techniques utilize chemical binders which then require that the mold halves be heat treated or baked in order to activate the binders. In order to pour molten metal into the mold when the cope and drag are latched together, runners are cut or molded into each half. Runners are connected to the mold cavity with a gate which is usually cut into the cope. A sprue is cut or molded through the cope to the runners such that when molten metal is poured into the hole through the cope, it travels through the runners and gate into the mold. Often risers are also cut into the mold halves. After pouring, risers provide a reservoir of molten metal to areas of the casting that solidify last. If metal is not supplied to these areas, the casting will have shrinkage defects.

Cores require different physical characteristics than molds; therefore, the binding systems used to make cores may be different from those used for molds. Cores must be able to withstand the strong forces of molten metal filling the mold, and often must be removed from small passages in the solidified casting. This means that the binding system used must produce strong, hard cores that will collapse for removal after the casting has hardened. Therefore, cores are typically formed from silica sand (and occasionally olivine or zircon sand), and strong chemical binders (U.S. EPA, 1992). The sand and binder mix is placed in a core box where it hardens into the desired shape and is removed. Hardening, or curing, is accomplished with heat, a chemical reaction, or a catalytic reaction. The major binding systems in use for molds and cores are discussed below.

Green Sand
Green sand is the most common molding process, making about 90% of castings produced in the U.S. Green sand is not used to form cores. Cores are formed using one of the chemical binding systems. Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85 to 95 percent silica (or olivine or zircon) sand, 4 to 10 percent bentonite clay, 2 to 10 percent carbonaceous materials such as powdered (sea) coal, petroleum products, corn starch or wood flour, and 2 to 5 percent water (AFS, 1996). The clay and water act as the binder, holding the sand grains together. The carbonaceous materials burn off when the molten metal is poured into the mold, creating a reducing atmosphere which prevents the metal from oxidizing while it solidifies (U.S. EPA, 1992).

Advantages and Disadvantages
Green sand, as exemplified by its widespread use, has a number of advantages over other casting methods. The process can be used for both ferrous and non-ferrous metal casting and it can handle a more diverse range of products than any other casting method. For example, green sand is used to produce both small precision castings and large castings of up to a ton. If uniform sand compaction and accurate control of sand properties are maintained, very close tolerances can be obtained. The process also has the advantage of requiring a relatively short time to produce a mold compared to many other processes. In addition, the relative simplicity of the process makes it ideally suited to a mechanized process (AFS, 1989).

Wastes Generated
Sand cores that are used in molds break down and become part of the mold sand. Foundries using green sand molds generate waste sand that becomes spent after it has been reused in the process a number of times, as a portion must be disposed of to prevent the build up of grains that are too fine. Waste chemically bonded core sands are also generated. Typically, damaged cores are not reusable and must be disposed as waste.

Figure 5: Process Flow and Potential Pollutant Outputs for Typical Green Sand Foundry

Make-up Sand

Raw Materials Inputs
• Sand
• Binders

Raw Materials Inputs
•Metal Scrap or Ingot
•Alloys
•Fluxing Agents

Particulates

Sand & Binder Mixing

Particulates

Scrap & Charge Preparation

Hydrocarbons, carbon monoxide, smoke

Core Forming

VOCs, HAPs

Metal Melting
•Cupola Furnace
•Electric-Arc Furnace
•Induction Furnace
•Reverberatory Furnace
•Crucible Furnace

Particulates, nitrogen oxides, carbon monoxides, metal oxide fumes, sulfur dioxide

Core Curing

Particulates

Mold Making

Mold & Core Assembly

Particulates, metal oxide fumes, carbon monoxide, VOCs, HAPs

Spent refractory material

Particulates, organic ompounds, HAPs, VOCs

Mold Pouring, Cooling

Tapping, Treatment, Slag & Dross Removal

Particulates, nitrogen oxides, carbon monoxides, metal oxide fumes, sulfur dioxide

Wet scrubber wastewater with high pH

Sand Preparation & Treatment
•Lump Knockout
•Screening
•Metal Removal
•Thermal Treatment
•Wet Scrubbing
•Other

Sand

Casting Shakeout

Particulates

Slag, dross, spent refractory material

Particulates

Riser Cutoff & Gate Removal

Scrap metal, spent tools, abrasives

Particulates, VOCs

Waste sand, fines and lumps, metals

Cleaning, Finishing, & Coating

Waste cleaning water with solvents, oil & grease, suspended solids

Spent solvents, abrasives, coatings, wastewater treatment sludge

Inspection & Shipping

Off-spec castings, packaging materials

Source: Adapted from Kotzin, Air Pollution Engineering Manual: Steel Foundries, 1992.

Particulate emissions are generated during mixing, molding and core making operations. In addition, gaseous and metal fume emissions develop when molten metal is poured into the molds and a portion of the metal volatilizes and condenses. When green sand additives and core sand binders come into contact with the molten metal, they produce gaseous emissions such as carbon monoxide, organic compounds, hydrogen sulfide, sulfur dioxide, nitrous oxide, benzene, phenols, and other hazardous air pollutants (HAPs) (Twarog, 1993). Wastewater containing metals and suspended solids may be generated if the mold is cooled with water.

Chemical Binding Systems

Chemical binding systems are primarily used for core making. Green sand is not used for cores because, chemically bound sand is stronger, harder, and can be more easily removed from the cavity after the metal has solidified. Almost every foundry using sand molds uses one or more of the chemical binding systems described below in constructing sand cores. Although some foundries also use chemical binding systems to construct molds, the much more simple, quick and inexpensive green sand molds described previously dominate the industry in terms of tons of castings produced. When chemical binding systems are used for mold making, the "shell-mold" system is most often used. Chemical bonding systems work through either thermal setting, chemical or catalytic reactions. The major thermal setting systems include: oil-bake, shell core/mold, hot box, and warm box. The major catalytic systems are the no-bake and cold box systems (U.S. EPA, 1993).

Oil-Bake

The traditional method used to produce cores is the oil-bake, or core-oil system. The oil-bake system uses oil and cereal binders mixed with sand. The core is shaped in a core box and then baked in an oven to harden it. Oils used can be natural, such as linseed oil, or synthetic resins, such as phenolic resins. The oil-bake system was used almost exclusively before 1950, but has now been largely replaced by other chemical binding systems (U.S. EPA, 1981).

Shell Core

The shell core system uses sand mixed with synthetic resins and a catalyst. The resins are typically phenolic or furan resins, or mixtures of the two. Often the shell core sand is purchased as dry coated sand. The catalyst is a weak aqueous acid such as ammonium chloride. The sand mixture is shaped in a heated metal core box. Starting from the outside edge of the core box and moving through the sand towards the center of the core box, the heat begins to cure the sand mix into a hard mass. When the outside 1/8 to 3/16 inches of sand has been cured, the core box is inverted. The uncured sand pours out of the core box leaving a hard sand core shell behind. The shell core is then removed from the core box, allowed to cure for an addition few minutes and is then ready for placement in the mold (LaRue, 1989). The system has the

advantage of using less sand and binders than other systems; however, shell sand may be more expensive than sand used in other sand processes.

Shell Mold
The shell mold system is similar to the shell core system, but is used to construct molds instead of cores. In this process, metal pattern halves are preheated, coated with a silicone emulsion release agent, and then covered by the resin-coated sand mixture. The heat from the patterns cures the sand mix and the mold is removed after the desired thickness of sand is obtained. The silicone emulsion acts as a mold release allowing the shell mold to be removed from the pattern after curing (LaRue, 1989).

Hot Box Core
The hot box process uses a phenolic or furan resin and a weak acid catalyst that are mixed with sand to coat the surface of the grains. The major difference between this system and the shell core system is that the core box is heated to about 450 to 550 °F until the entire core has become solidified (Twarog, 1993). The system has the advantage of very fast curing times and a sand mix consistency allowing the core boxes to be filled and packed quickly. Therefore, the system is ideal for automation and the mass production of cores. The disadvantage is that more sand and binder is used in this system than in the shell core system.

Warm Box Core
The warm box system is essentially the same as the hot box system, but uses a different catalyst. The catalysts used allow the resin binders to cure at a lower temperature (300 to 400 °F). As with the hot box, the resins used are phenolic and furan resins. Either copper salts or sulfonic acids are used as a catalyst. The advantage over hot box is reduced energy costs for heating (Twarog, 1993).

Cold Box
The cold box process is relatively new to the foundry industry. The system uses a catalytic gas to cure the binders at room temperature. A number of different systems are available including phenolic urethane binder with carbon dioxide gas as the catalyst. Other systems involve different binders (e.g., sodium silicate) and gases, such as sulfur dioxide and dimethylethylamine (DMEA), many of which are flammable or irritants. Compared to other chemical systems, the cold box systems have a short curing time (lower than ten seconds) and therefore are well suited to mass production techniques (AFS, 1981). In addition, the absence of costly oven heating can result in substantial energy savings.

No-Bake

The no-bake or air set binder systems allow curing at room temperature without the use of reactive gases. The no-bake system uses either acid catalysts or esters to cure the binder. The acid catalysts are typically benzene, toluene, sulfonic or phosphoric acids. Binders are either phenolic resins, furan resins, sodium silicate solution or alkyd urethane. The system has the advantage of substantial savings in energy costs (Twarog, 1993).

Advantages and Disadvantages

Cores are necessarily constructed using chemical binders. Molds, however, may be constructed with chemical binders or green sand. The advantages to using chemically bonded molds over green sand molds may include: a longer storage life for the molds, a potentially lower metal pouring temperature, and molds having better dimensional stability and surface finish. Disadvantages include the added costs of chemical binders, the energy costs for curing the binders, added difficulties to reclaim used sand, and environmental and worker safety concerns for air emissions associated with binder chemicals during curing and metal pouring.

Wastes Generated

Solid wastes generated include broken cores and sand that has set up prematurely or inadequately. Waste resins and binders can be generated from spills, residuals in containers, and outdated materials. In addition to fugitive dust from the handling of sand, mold and core making using chemical binding systems may generate gaseous emissions such as carbon monoxide, VOCs and a number of gasses listed as hazardous air pollutants (HAPs) under the Clean Air Act. Emissions occur primarily during heating or curing of the molds and cores, removal of the cores from core boxes, cooling, and pouring of metal into molds (Twarog, 1993). The specific pollutants generated depends on the type of binding system being used. Section III.B Table 4 lists typical air emissions that may be expected from each major type of chemical binding system. Wastewater containing metals, suspended solids, and phenols may be generated if molds are cooled with water.

Permanent Mold Casting

In permanent mold casting, metal molds are used repeatedly. Although the molds deteriorate over time, they can be used to make thousands of castings before being replaced. The process is similar to die casting (see Section III.A.6 on Die Casting) with the exception being that gravity is used to fill the mold rather than external pressure. Permanent molds are designed to be opened, usually on a hinge, so that the castings can be removed. Permanent molds can be used for casting both ferrous and nonferrous metals as long as the mold metal has a higher melting point than the casting metal. Cores from permanent molds can be sand, plaster, collapsible metal or, soluble salts.

When cores are not reusable, the process is often referred to as semipermanent mold casting (AFS, 1981).

Since the process is relatively simple after the mold has been fabricated, and since large numbers of castings are usually produced, permanent mold casting is typically an automated process. The sequence of operations includes an initial cleaning of the mold followed by preheating and the spraying or brushing on of a mold coating. The coating serves the purpose of insulating the molten metal from the relatively cool, heat conducting mold metal. This allows the mold to be filled completely before the metal begins to solidify. The coatings also help produce good surface finish, act as a lubricant to facilitate casting removal, and allow any air in the mold to escape via space between the mold and coating. After coating, cores are then inserted and the mold is closed. The metal is poured and allowed to solidify before opening and ejecting the casting (LaRue, 1989).

Materials
Mold metals are typically made of cast iron. The molds can be very simple or can have a number of sophisticated features, such as ejector pins to remove castings, water cooling channels and sliding core pins. Coatings are typically mixtures of sodium silicate and either vermiculite, talc, clay or bentonite (AFS, 1981).

Advantages and Disadvantages
Permanent molds have the obvious advantage of not requiring the making of a new mold (and the associated time and expenses) for every casting. The elimination of the mold making process results in a more simple overall casting process, a cleaner work environment, and far less waste generation. Because molten metal cools and solidifies much faster in a permanent mold than in a sand mold, a more dense casting with better mechanical properties is obtained. The process can also produce castings with a high level of dimensional accuracy and good surface finish (AFS, 1981). One disadvantage is the high cost of tooling, which includes the initial cost of casting and machining the permanent mold. In addition, the shapes and sizes of castings are limited due to the impossibility of removing certain shapes from the molds (USITC, 1984).

Wastes Generated
Compared to sand casting operations, relatively little waste is generated in the permanent mold process. Some foundries force cool the hot permanent molds with water sprayed or flushed over the mold. The waste cooling water may pick up contaminants from the mold such as metals and mold coatings. Fugitive dust and waste sand or plaster are generated if cores are fabricated of sand or plaster, respectively. Waste coating material may also be generated during cleaning of the mold.

Plaster Mold Casting

The conventional plaster molding process is similar to the sand molding processes. In cope and drag flasks, a plaster slurry mix is poured over the pattern halves. When the plaster has set, the patterns are removed and the mold halves are baked to remove any water (USITC, 1984). Since even small amounts of water will, when quickly heated during pouring, expand to steam and adversely affect the casting, drying is a critical step in plaster mold casting. Oven temperatures may be as high as 800°F for as long as 16 to 36 hours. As in the sand mold processes, the cores are inserted, and the dried mold halves are attached prior to pouring the molten metal. The plaster molds are destroyed during the shakeout process. Plaster or sand cores may be used in the process.

The conventional plaster molding process described here is the most common of a number of plaster mold casting processes in use. Other processes include the foamed plaster casting process, the Antioch casting process and the match plate pattern casting process (AFS, 1981).

Materials
The plasters used in plaster mold casting are very strong, hard gypsum (calcium sulfate) cements mixed with either fibrous talcs, finely ground silica, pumice stone, clay or graphite. Plaster mixtures may also be comprised of up to 50 percent sand (AFS, 1981).

Advantages and Disadvantages
The plaster mold process can produce castings with excellent surface detail, complex and intricate configurations, and high dimensional accuracy. Plaster mold castings are also light, typically under 20 pounds (USITC, 1994). The process is limited to nonferrous metals because ferrous metals will react with the sulfur in the gypsum, creating defects on the casting surface (AFS, 1981). Plaster mold casting is more expensive than sand casting, and has a longer process time from mold construction to metal pouring. The process is only used, therefore, when the desired results cannot be obtained through sand casting or when the finer detail and surface finish will result in substantial savings in machining costs.

Wastes Generated
Waste mold plaster and fugitive dust can be generated using this process. Waste sand can also be generated, depending on the type of cores used.

Investment/Lost Wax Casting

Investment casting processes use a pattern or replica that is consumed, or lost, from the mold material when heated. The mold-making process results in a

one-piece destroyable mold. The most common type of investment casting, the lost wax process, uses patterns fabricated from wax. Plastic patterns, however, are also fairly common in investment casting.

The process begins with the production of a wax or plastic replica of the part. Replicas are usually mass produced by injecting the wax or plastic into a die (metal mold) in a liquid or semi-liquid state. Replicas are attached to a gating system (sprue and runners) constructed of the same material to form a tree assembly (see Figure 6). The assembly is coated with a specially formulated heat resistant refractory slurry mixture which is allowed to harden around the wax or plastic assembly forming the mold (USITC, 1984).

In the investment *flask* casting method, the assembly is placed in a flask and then covered with a refractory slurry which is allowed to harden (see Figure 6). In the more common investment *shell* casting method, the assembly is dipped in a refractory slurry and sand is sifted onto the coated pattern assembly and allowed to harden. This process is repeated until the desired shell thickness is reached (LaRue, 1989). In both methods, the assembly is then melted out of the mold. Some investment casting foundries are able to recover the melted wax and reuse a portion in the pattern making process. The resulting mold assemblies are then heated to remove any residual pattern material and to further cure the binder system. The mold is then ready for the pouring of molten metal into the central sprue which will travel through the individual sprues and runners filling the mold.

Although normally not necessary, cores can be used in investment casting for complex interior shapes. The cores are inserted during the pattern making step. The cores are placed in the pattern die and pattern wax or plastic is injected around the core. After the pattern is removed from the die, the cores are removed. Cores used in investment casting are typically collapsible metal assemblies or soluble salt materials which can be leached out with water or a dilute hydrochloric acid solution.

In addition to the investment flask and shell mold casting methods described above, a number of methods have been developed which use reusable master patterns. These processes were developed to eliminate production of expendable patterns, one of the most costly and time-consuming steps in the casting process. One process, called the Shaw Process, uses a refractory slurry containing ethyl silicate. The slurry cures initially to a flexible gel which can be removed from the pattern in two halves. The flexible mold halves can then be further cured at high temperatures until a hard mold is formed ready for assembly and pouring (AFS, 1981).

Figure 6: Investment Flask and Shell Casting
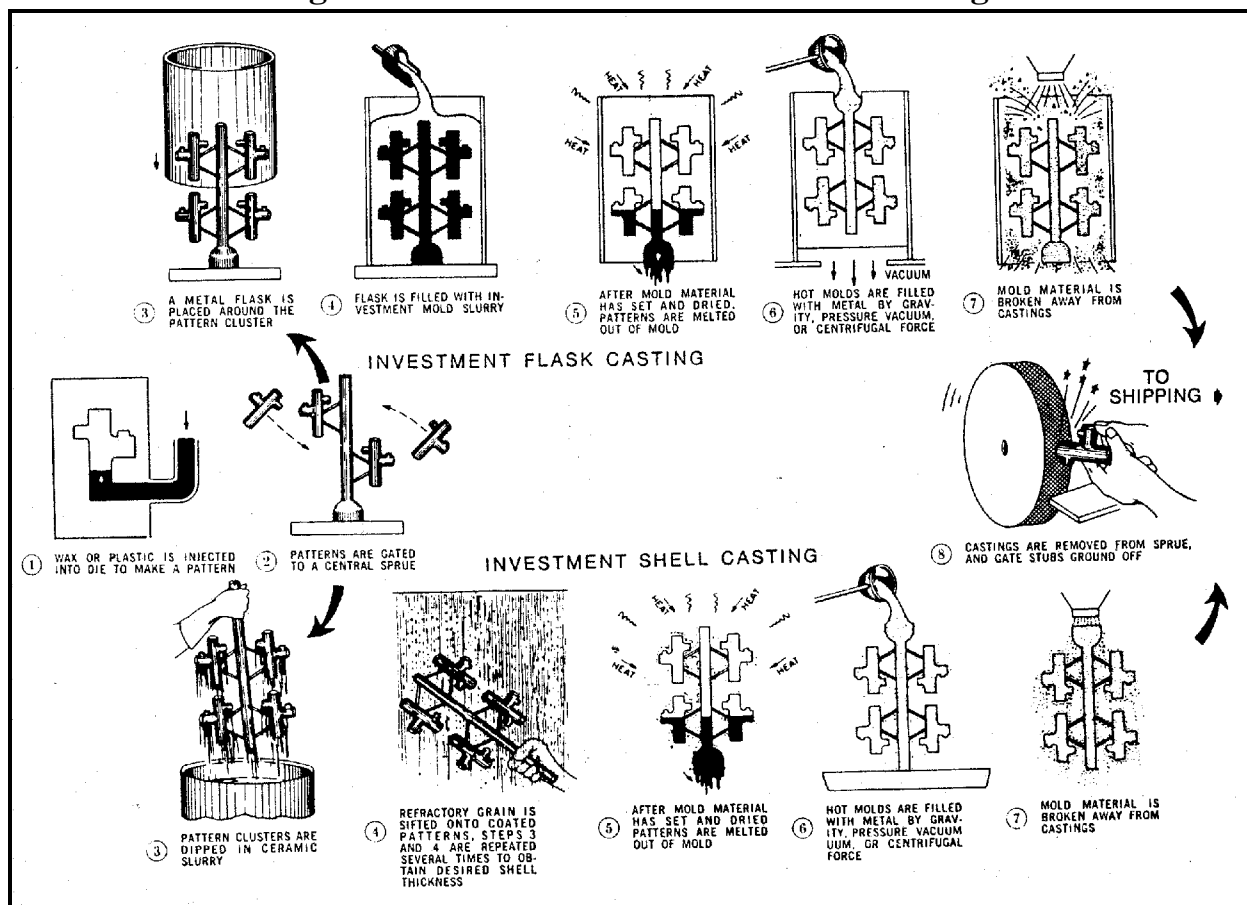
Source: American Foundrymen's Society, 1981.

Materials

The refractory slurries used in both investment flask and shell casting are comprised of binders and refractory materials. Refractory materials include silica, aluminum silicates, zircon, and alumina. Binders include silica sols (very small silica particles suspended in water), hydrolyzed ethyl silicate, sodium and potassium silicate, and gypsum type plasters. Ethyl silicate is typically hydrolyzed at the foundry by adding alcohol, water, and hydrochloric acid to the ethyl silicate as a catalyst (AFS, 1981).

Pattern materials are most commonly wax or polystyrene. Wax materials can be synthetic, natural, or a combination. Many different formulations are available with varying strengths, hardness, melting points, setting times, and compatibilities, depending on the specific casting requirements.

Advantages and Disadvantages

The investment casting process produces castings with a higher degree of dimensional accuracy than any other casting process. The process can also produce castings with a high level of detail and complexity and excellent surface finish. Investment casting is used to create both ferrous and nonferrous precision pieces such as dental crowns, fillings and dentures, jewelry, and scientific instruments. The costs of investment casting are generally higher than for other casting processes due in part to the high initial costs of pattern die-making (USITC, 1984). In addition, the relatively large number of steps in the process is less amenable to automation than many other casting methods.

Wastes Generated

Waste refractory material, waxes, and plastic are the largest volume wastes generated. Air emissions are primarily particulates. Wastewater with suspended and dissolved solids and low pH may also be generated if soluble salt cores are used.

Lost Foam Casting

The lost foam casting process, also known as Expanded Polystyrene (EPS) casting, and cavityless casting, is a relatively new process that is gaining increased use. The process is similar to investment casting in that an expendable polystyrene pattern is used to make a one-piece expendable mold. As in investment casting, gating systems are attached to the patterns, and the assembly is coated with a specially formulated gas permeable refractory slurry. When the refractory slurry has hardened, the assembly is positioned in a flask, and unbonded sand is poured around the mold and compacted into any internal cavities. Molten metal is then poured into the polystyrene pattern which vaporizes and is replaced by the metal (see Figure 7). When the metal has solidified, the flask is emptied onto a steel grate for shakeout. The loose sand falls through the grate and can be reused without treatment. The refractory material is broken away from the casting in the usual manner (AFS, 1981).

Materials

Refractory slurries for lost foam casting must produce a coating strong enough to prevent the loose sand around the coated assembly from collapsing into the cavity as the pattern vaporizes. Coatings must also be permeable to allow the polystyrene vapors to escape from the mold cavity, through the coating, into the sand and out of the flask. Flasks for this process have side vents which allow the vapors to escape (AFS, 1981).

Figure 7: Lost Foam Casting Cross Sections
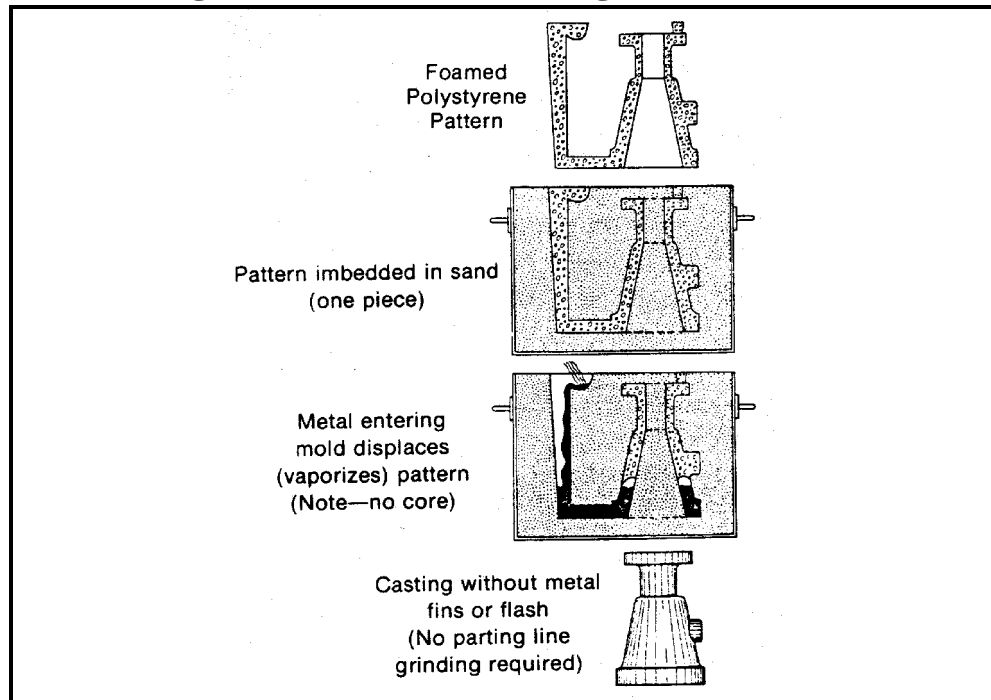
Source: American Foundrymen's Society, 1981.

Polystyrene patterns can be fabricated from polystyrene boards or by molding polystyrene beads. Patterns from boards are fabricated using normal pattern forming tools (see Section III.A.1). The boards are available in various sizes and thicknesses, and can be glued together to increase thickness if needed. Molded polystyrene patterns begin as small beads of expandable polystyrene product. The beads are pre-expanded to the required density using a vacuum, steam, or hot air processes. In general, the aim is to reduce the bead density as much as possible in order to minimize the volume of vapors to be vented during casting. If vapors are generated faster than can be vented, casting defects will result. The expanded polystyrene beads are blown into a cast aluminum mold. Steam is used to heat the beads causing them to expand further, fill void areas, and bond together. The mold and pattern are allowed to cool, and the pattern is ejected (AFS, 1981).

Advantages and Disadvantages
The lost foam process can be used for precision castings of ferrous and nonferrous metals of any size. In addition to being capable of producing highly accurate, complex castings with thin walls, good surface finish, and no parting lines, there are numerous practical advantages to the process. For example, there are far fewer steps involved in lost foam casting compared to sand casting. Core making and setting is not necessary, nor is the mixing of

large amounts of sand and binders. Shakeout and sand handling is a matter of pouring out the sand which is mostly reusable without any treatment since binders are not used. Some portion of sand may need to be removed to avoid the buildup of styrene in the sand. The flasks used are less expensive and easier to use since there are no cope and drag halves to be fastened together. The reduced labor and material costs make lost foam casting an economical alternative to many traditional casting methods. Although the potential exists for other metals to be cast, currently only aluminum and gray and ductile iron are cast using this method (AFS, 1981). In addition there are some limitations in using the technique to cast low carbon alloys (SFSA, 1997).

Wastes Generated
The large quantities of polystyrene vapors produced during lost foam casting can be flammable and may contain hazardous air pollutants (HAPs). Other possible air emissions are particulates related to the use of sand. Waste sand and refractory materials containing styrene may also be generated.

III.A.3. Furnace Charge Preparation and Metal Melting

Foundries typically use recycled scrap metals as their primary source of metal, and use metal ingot as a secondary source when scrap is not available. The first step in metal melting is preparation of the scrap materials. Preparation, which also may be done by the foundry's metal supplier, consists of cutting the materials to the proper size for the furnace and cleaning and degreasing the materials. Cleaning and degreasing can be accomplished with solvents or by a precombustion step to burn off any organic contaminants (Kotzin, 1992). Prepared scrap metal is weighed and additional metal, alloys, and flux may be added prior to adding the metal to the furnace. Adding metal to a furnace is called "charging." (Alloys may also be added at various stages of the melt or as the ladle is filled.)

Flux is a material added to the furnace charge or to the molten metal to remove impurities. Flux unites with impurities to form dross or slag, which rises to the surface of the molten metal where it is removed before pouring (LaRue, 1989). The slag material on the molten metal surface helps to prevent oxidation of the metal. Flux is often chloride or fluoride salts that have an affinity to bind with certain contaminants. The use of salt fluxes may result in emissions of acid gasses.

Five types of furnaces are commonly used to melt metal in foundries: cupola, electric arc, reverberatory, induction and crucible (see Figure 8). Some foundries operate more than one type of furnace and may even transfer molten metal between furnace types in order to make best use of the best features of each.

Cupola Furnaces

The cupola furnace is primarily used to melt gray, malleable, or ductile iron. The furnace is a hollow vertical cylinder on legs and lined with refractory material. Hinged doors at the bottom allow the furnace to be emptied when not in use. When charging the furnace, the doors are closed and a bed of sand is placed at the bottom of the furnace, covering the doors. Alternating layers of coke for fuel and scrap metal, alloys and flux are placed over the sand. Although air, or oxygen enriched air, is forced through the layers with a blower, cupolas require a reducing atmosphere to maintain the coke bed. Heat from the burning coke melts the scrap metal and flux, which drip to the bottom sand layer. In addition, the burning of coke under reducing conditions raises the carbon content of the metal charge to the casting specifications. A hole level with the top of the sand allows molten metal to be drained off, or "tapped." A higher hole allows slag to be drawn off. Additional charges can be added to the furnace as needed (LaRue, 1989).

Electric Arc Furnaces

Electric arc furnaces are used for melting cast iron or steel. The furnace consists of a saucer-shaped hearth of refractory material for collecting the molten metal with refractory material lining the sides and top of the furnace. Two or three carbon electrodes penetrate the furnace from the top or sides. The scrap metal charge is placed on the hearth and melted by the heat from an electric arc formed between the electrodes. When the electric arc comes into contact with the metal, it is a direct-arc furnace and when the electric arc does not actually touch the metal it is an indirect-arc furnace. Molten metal is typically drawn off through a spout by tipping the furnace. Alloying metal can be added, and slag can be removed, through doors in the walls of the furnace (LaRue, 1989). Electric arc furnaces have the advantage of not requiring incoming scrap to be clean. One disadvantage is that they do not allow precise metallurgical adjustments to the molten metal.

Reverberatory Furnaces

Reverberatory furnaces are primarily used to melt large quantities of nonferrous metals. Metal is placed on a saucer-shaped hearth lined with refractory material on all sides. Hot air and combustion gasses from oil or gas burners are blown over the metal and exhausted out of the furnace. The heat melts the metal and more charge is added until the level of molten metal is high enough to run out of a spout in the hearth and into a well from which it can be ladled out (LaRue, 1989).

Induction Furnaces

Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnaces, but all create a strong magnetic field by passing an electric current through a coil wrapped around the furnace. The magnetic field in turn creates a voltage across and subsequently an

electric current through the metal to be melted. The electrical resistance of the metal produces heat which melts the metal. Induction furnaces are very efficient and are made in a wide range of sizes (LaRue, 1989). Induction furnaces require cleaner scrap than electric arc furnaces, however, they do allow precise metallurgical adjustments.

Crucible Furnaces
Crucible furnaces are primarily used to melt smaller amounts of nonferrous metals than other furnace types. The crucible or refractory container is heated in a furnace fired with natural gas or liquid propane. The metal in the crucible melts, and can be ladled from the crucible or poured directly by tipping the crucible (LaRue, 1989).

Wastes Generated
Cupola, reverberatory and electric arc furnaces may emit particulate matter, carbon monoxide, hydrocarbons, sulfur dioxide, nitrogen oxides, small quantities of chloride and fluoride compounds, and metallic fumes from the condensation of volatilized metal and metal oxides. Induction furnaces and crucible furnaces emit relatively small amounts of particulates, hydrocarbons, and carbon monoxide emissions. The highest concentration of furnace emissions occur when furnaces are opened for charging, alloying, slag removal, and tapping (Kotzin, 1992). Particulate emissions can be especially high during alloying and the introduction of additives. For example, if magnesium is added to molten metal to produce ductile iron, a strong reaction ensues, with the potential to release magnesium oxides and metallic fumes (NADCA, 1996).

Furnace emissions are often controlled with wet scrubbers. Wet scrubber wastewater can be generated in large quantities (up to 3,000 gallons per minute) in facilities using large cupola furnaces. This water may contain metals and phenols, and is typically highly alkaline or acidic and is neutralized before being discharged to the POTW (AFS Air Quality Committee, 1992). Non-contact cooling water with little or no contamination may also be generated.

Scrap preparation using thermal treatment will emit smoke, organic compounds and carbon monoxide. Other wastes may include waste solvents if solvents are used to prepare metal for charging. Slag is also generated during metal melting operations. Hazardous slag can be generated if the charge materials contain enough toxic metals such as lead and chromium or if calcium carbide is used in the metal to remove sulfur compounds (see Section III.B.1) (U.S. EPA, 1992).

Figure 8: Sectional Views of Melting Furnaces

Cupola

Electric Indirect-Arc

Induction

Reverberatory
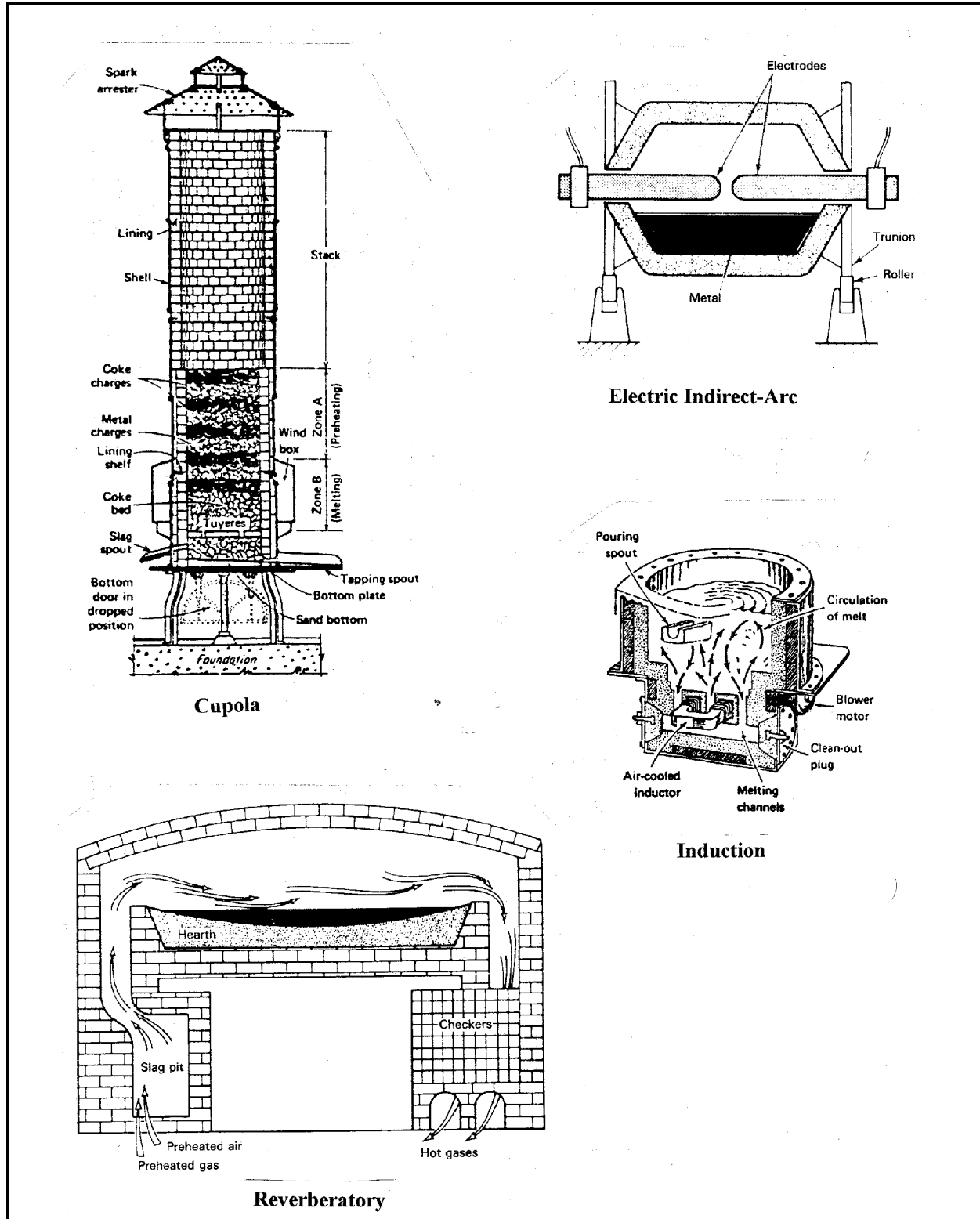
Source: American Foundrymen's Society, 1989.

III.A.4. Shakeout, Cooling and Sand Handling

For those foundries using sand molding and core making techniques, castings need to be cooled and separated from the sand mold. After molten metal has been ladled into the mold and begins to solidify, it is transported to a cooling area where the casting solidifies before being separated from the mold. Larger, more mechanized foundries use automatic conveyor systems to transfer the casting and mold through a cooling tunnel on the way to the shakeout area. Less mechanized foundries allow the castings to cool on the shop floor. In the shakeout area, molds are typically placed on vibrating grids or conveyors to shake the sand loose from the casting. In some foundries, the mold may be separated from the casting manually (EPA, 1986).

Sand casting techniques can generate substantial volumes of waste sand. Many foundries reuse a large portion of this sand and only remove a small portion as waste. Waste sand removed from the foundry is primarily made up of fine grains that build up as the sand is reused over and over. Most foundries, therefore, have a large multi-step sand handling operation for capturing and conditioning the reusable sand. Larger foundries often have conveyorized sand-handling systems working continuously. Smaller, less mechanized foundries often use heavy equipment (e.g., front-end loaders) in a batch process (U.S. EPA, 1992). Increasingly, foundry waste sand is being sent off-site for use as a construction material (see Section V).

Sand handling operations receive sand directly from the shakeout step or from an intermediate sand storage area. A typical first step in sand handling is lump knockout. Sand lumps occur when the binders used in sand cores only partially degrade after exposure to the heat of molten metal. The lumps, or core butts, may be crushed and recycled into molding sand during this step. They can also be disposed as waste material. A magnetic separation operation is often used in ferrous foundries to remove pieces of metal from the sand. Other steps involve screening to remove fines that build up over time, and cooling by aeration. In addition, some foundries treat mold and core sand thermally to remove binders and organic impurities (U.S. EPA, 1992).

Wastes Generated
Shakeout, cooling, and sand handling operations generate waste sand and fines possibly containing metals. In addition, particulate emissions are generated during these operations. If thermal treatment units are used to reclaim chemically bonded sands, emissions such as carbon monoxide, organic compounds, and other gasses can be expected.

III.A.5. Quenching, Finishing, Cleaning and Coating

Rapid cooling of hot castings by quenching in a water bath is practiced by some foundries and die casters to cool and solidify the casting rapidly (to speed the process) and to achieve certain metallurgical properties. The water bath may be plain water or may contain chemical additives to prevent oxidation.

Some amount of finishing and cleaning is required for all castings; however, the degree and specific types of operations will depend largely on the casting specifications and the casting process used. Finishing and cleaning operations can be a significant portion of the overall cost to produce a casting. Foundries, therefore, often search for casting techniques and mold designs that will reduce the finishing needed.

Finishing operations begin once the casting is shaken out and cooled. Hammers, band saws, abrasive cutting wheels, flame cut-off devices, and air-carbon arc devices may be used to remove the risers, runners, and sprues of the gating system. Metal fins at the parting lines (lines on a casting corresponding to the interface between the cope and drag of a mold) are removed with chipping hammers and grinders. Residual refractory material and oxides are typically removed by sand blasting or steel shot blasting, which can also be used to give the casting a uniform and more attractive surface appearance (U.S. EPA, 1992).

The cleaning of castings precedes any coating operations to ensure that the coating will adhere to the metal. Chemical cleaning and coating operations are often contracted out to off-site firms, but are sometimes carried out at the foundries. Scale, rust, oxides, oil, grease, and dirt can be chemically removed from the surface using organic solvents (typically chlorinated solvents, although naphtha, methanol, and toluene are also used), emulsifiers, pressurized water, abrasives, alkaline agents (caustic soda, soda ash, alkaline silicates, and phosphates), or acid pickling. The pickling process involves the cleaning of the metal surface with inorganic acids such as hydrochloric acid, sulfuric acid, or nitric acid. Castings generally pass from the pickling bath through a series of rinses. Molten salt baths are also used to clean complex interior passages in castings (U.S. EPA, 1992).

Castings are often given a coating to inhibit oxidation, resist deterioration, or improve appearance. Common coating operations include: painting, electroplating, electroless nickel plating, hard facing, hot dipping, thermal spraying, diffusion, conversion, porcelain enameling, and organic or fused dry-resin coating (U.S. EPA, 1992).

Wastes Generated
Casting quench water may contain phenols, oil and grease, suspended solids, and metals (e.g., copper, lead, zinc). Metal-bearing sludges may be generated when quench baths are cleaned out (EPA, 1995).

Finishing operations may generate particulate air emissions. Wastewater may contain cutting oils, ethylene glycol, and metals. Solid wastes include metal chips and spent cutting oils (EPA, 1995).

Cleaning and coating may generate air emissions of VOCs from painting, coating and solvent cleaning; acid mists and metal ion mists from anodizing, plating, polishing, hot dip coating, etching, and chemical conversion coating. Wastewater may contain solvents, metals, metal salts, cyanides, and high or low pH. Solid wastes include cyanide and metal-bearing sludges, spent solvents and paints, and spent plating baths (EPA, 1995).

III.A.6. Die Casting

The term "die casting" usually implies "pressure die casting." The process utilizes a permanent die (metal mold) in which molten metal is forced under high pressure. Dies are usually made from two blocks of steel, each containing part of the cavity, which are locked together while the casting is being made. Retractable and removable cores are used to form internal surfaces. The metal is held under pressure until it cools and solidifies. The die halves are then opened and the casting is removed, usually by means of an automatic ejection system. Dies are preheated and lubricated before being used, and are either air- or water-cooled to maintain the desired operating temperature (Loper, 1985). Metal is typically melted on site from prealloyed ingot, or by blending the alloying constituents (or occasionally metal scrap). Some aluminum die casters, however, purchase molten aluminum and store it on site in a holding furnace (NADCA, 1996). Two basic types of die casting machines are used: hot chamber and cold-chamber (see Figure 9).

Die casting machines
Hot-chamber die casting machines are comprised of a molten metal reservoir, the die, and a metal-transferring device which automatically withdraws molten metal from the reservoir and forces it under pressure into the die. A steel piston and cylinder system is often used to create the necessary pressure within the die. Pressures can range from a few hundred to over 5,000 psi. Certain metals, such as aluminum alloys, zinc alloys, and pure zinc cannot be used in hot-chamber die casting because they rapidly attack the iron in the piston and cylinder. These metals, therefore, require a different type of casting machine, called a gooseneck. A gooseneck machine utilizes a cast-iron channel to transfer the molten metal from the reservoir to the die (see Figure 9(b)). After the gooseneck is brought into contact with the die,

compressed air is applied to the molten metal. Pressures are typically in the range of 350 to 500 psi (Loper, 1985).

Cold chamber machines have molten metal reservoirs separate from the casting machine. Just enough metal for one casting is ladled by hand or mechanically into a small chamber, from which it is forced into the die under high pressure (see Figure 9(a)). Pressure is produced through a hydraulic system connected to a piston, and is typically in the range of a few thousand psi to 10,000 psi. In cold chamber machines, the metal is just above the melting point and is in a slush-like state. Since the metal is in contact with the piston and cylinder for only a short period of time, the process is applicable to aluminum alloys, magnesium alloys, zinc alloys, and even high melting-point alloys such as brasses and bronzes (Loper, 1985).

Figure 9: Cold (a), and Hot Chamber (b), Die Casting Machines
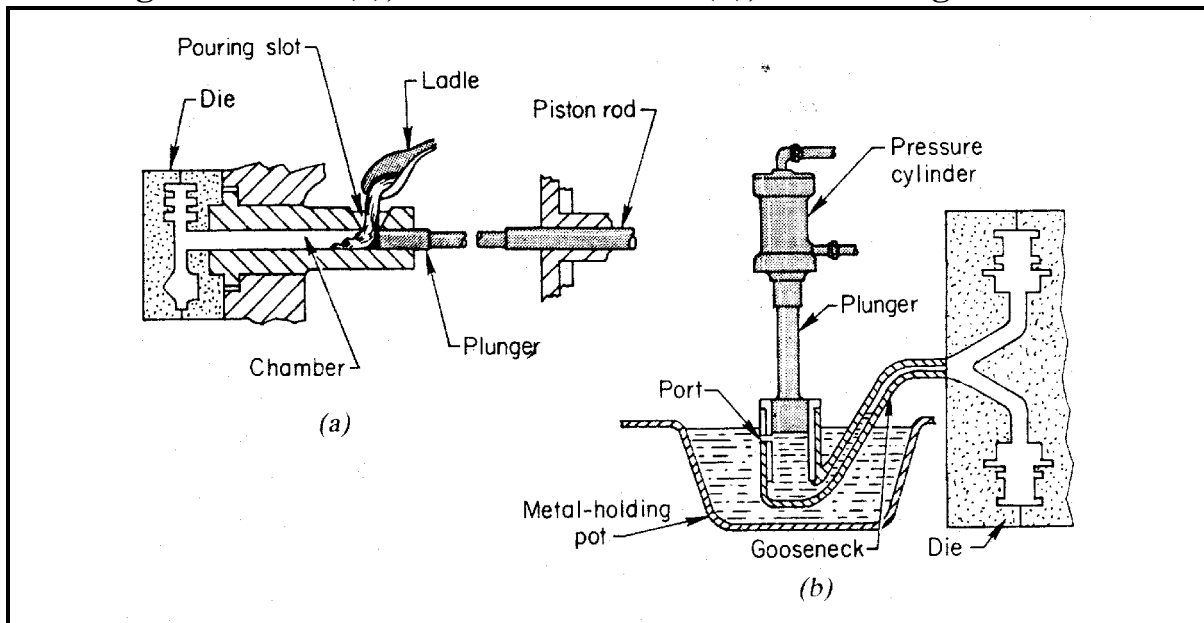
Source: American Foundrymen's Society, 1981.

Die Lubrication
Proper lubrication of dies and plungers is essential for successful die casting. Die lubrication affects the casting quality, density, and surface finish, the ease of cavity fill, and the ease of casting ejection. Proper lubrication can also speed the casting rate, reduce maintenance, and reduce build up of material on the die face (Street, 1977).

Die lubrication can be manual or automatic. In manual systems, the die casting machine operator uses a hand held spray gun to apply lubricant to the

die surface just before the die is closed. Automatic systems use either fixed or reciprocating spray systems to apply lubricant (Allsop, 1983).

There are many types and formulations of lubricants on the market. No one lubricant meets the requirements for all die casters. The specific lubricant formulation used depends on a number of factors, including: the metal being cast, the temperatures of casting, the lubricant application method, the surface finish requirements, the complexity of the casting, and the type of ejection system. Although specific formulations are proprietary, in general, lubricants are a mixture of a lubricant and a carrier material. Formulations may also include additives to inhibit corrosion, increase stability during storage, and resist bacterial degradation (Kaye, 1982).

Lubricants are mostly carrier material which evaporates upon contact with the hot die surface, depositing a thin uniform coating of die lubricant on the die face. Typical ratios of carrier to lubricant are about 40 to 1 (Kaye, 1982).

Both water-based lubricants and solvent-based lubricants are in use today. Solvents, however, are largely being phased out due to health and fire concerns associated with the large amounts of solvent vapors released. Water-based lubricants are now used almost exclusively in the U.S. Lubricating materials are typically mineral oils and waxes in water emulsions. Silicone oils and synthetic waxes are finding increased use. In addition, research is under way to develop a permanent release coating for die surfaces which will eliminate the need for repeated lubricant application (Kaye, 1982).

Advantages and Disadvantages
Die casting is not applicable to steel and high melting point alloys. Pressure dies are very expensive to design and produce, and the die casting machines themselves are major capital investments (LaRue, 1989). Therefore, to compete with other casting methods, it must be more economical to produce a component by virtue of higher production rates, or the finished components must be superior to those produced using other methods -- often, it is a combination of both factors (USITC, 1984).

Once the reusable die has been prepared, the die casting process can sustain very high production rates. Castings can be made at rates of more than 400 per hour. There is a limit, however, to the number of castings produced in a single die depending on the die design, the alloys being casted, and the dimensional tolerances required. The useable life span of a die can range from under 1,000 to over 5,000,000 castings or "shots." (Allsop, 1983) Therefore, the design of the die itself is critical not only for producing high quality castings but also in ensuring the economic viability of the production process. Die design is a very complex exercise. In addition to the design of the component geometry and constituent materials, numerous factors related to

the die itself must be considered, including: the type of alloys, the temperature gradients within the die, the pressure and velocity of the molten metal when it enters the die, the technique for ejecting the casting from the die, and the lubrication system used (Street, 1977). Computer-aided design and modeling of die designs is now commonplace and has played an important role in advancing the technology.

One major advantage of die casting over other casting methods is that the produced castings can have very complex shapes. The ability to cast complex shapes often makes it possible to manufacture a product from a single casting instead of from an assembly of cast components. This can greatly reduce casting costs as well as costs associated with fabrication and machining. Furthermore, die casting produces castings having a high degree of dimensional accuracy and surface definition compared to other casting methods, which may also reduce or eliminate costly machining steps. Finally, castings with relatively thin wall sections can be produced using the die casting method. This can result in substantial savings in material costs and reductions in component weight (Allsop, 1983).

<u>Wastes Generated</u>
Wastes generated during metal melting will be similar to those of metal melting in foundries, depending on the particular furnace used. Relatively little waste is generated in the actual die casting process compared to other metal casting processes. However, some gaseous and fume emissions occur during metal injection. Metal oxide fumes are released as some of the metal vaporizes and condenses. Gaseous emissions can originate from: the molten metal itself; the evolution of chemicals from the lubricant as it is sprayed onto the hot metal die; and as the molten metal contacts the lubricant (NADCA, 1996).

III.B. Raw Materials Inputs and Pollution Outputs

Raw material inputs and pollutant outputs differ for foundries and die casters. The major difference lies in the use of permanent molds by die casting facilities which eliminates any need for large mold making operations and the handling, treatment and disposal of sand and other refractory materials. For this reason, the material inputs and pollutant outputs of permanent mold casting foundries will likely be more similar to those of die casting facilities. Table 4 summarizes the material inputs and pollution outputs discussed in this section.

III.B.1. Foundries

The main raw material inputs for foundries are sand and other core and mold refractory materials (depending of the particular processes used), metals in the form of scrap and ingot, alloys, and fuel for metal melting. Other raw material inputs include binders, fluxing agents, and pattern making materials.

Air Emissions

Air emissions at foundries primarily arise from metal melting, mold and core making, shakeout and sand handling, and the cleaning and finishing of cast parts (Kotzin, 1992).

Furnaces and Metal Melting
Furnace air emissions consist of the products of combustion from the fuel and particulate matter in the form of dusts, metallics, and metal oxide fumes. Carbon monoxide and organic vapors may also arise if oily scrap is charged to the furnace or preheat system (AP-42, 1993). Particulates will vary according to the type of furnace, fuel (if used), metal melted, melting temperature, and a number of operating practices. Air emissions from furnaces and molten metal can often be reduced by applying a number of good operating practices (see Section V.A). Particulates can include fly ash, carbon, metallic dusts, and fumes from the volatilization and condensation of molten metal oxides. In steel foundries, these particulates may contain varying amounts of zinc, lead, nickel, cadmium, and chromium (Kotzin, 1992). Carbon-steel dust can be high in zinc as a result of the use of galvanized scrap, while stainless steel dust is high in nickel and chromium. Painted scrap can result in particulates high in lead. Particulates associated with nonferrous metal production may contain copper, aluminum, lead, tin, and zinc. The particulate sizes of the oxide fumes are often very small (submicron) and, therefore, require high efficiency control devises (Licht, 1992).

Furnace air emissions are typically captured in ventilation systems comprised of hoods and duct work. Hoods and ducts are usually placed over and/or near the tapping spouts, and metal charging, slag removal, and pouring areas. Hoods can be permanently fixed at pouring stations or attached to the pouring ladle or crane through flexible duct work. Depending on the type of furnace and metals melted, these ventilation systems may be ducted to coolers to cool the hot combustion gases, followed by baghouses, electrostatic precipitators and/or wet scrubbers to collect particulates. Afterburners may also be used to control carbon monoxide and oil vapors (Licht, 1992).

Mold and Core Making
The major air pollutants generated during mold and core making are particulates from the handling of sand and other refractory materials, and VOCs from the core and mold curing and drying operations. VOCs, particulates, carbon monoxide, and other organic compounds are also emitted when the mold and core come into contact with the molten metal and while the filled molds are cooled (AP-42, 1993).

The use of organic chemical binding systems (e.g., cold box, hot box, no bake, etc.) may generate sulfur dioxide, ammonia, hydrogen sulfide, hydrogen cyanide, nitrogen oxides and large number of different organic compounds. Emissions occur primarily during heating and curing, removal of the cores from core boxes, cooling, and pouring the metal into molds and may include a number of gases listed as hazardous air pollutants (HAPs) under the Clean Air Act. Potential HAPs emitted when using chemical binding systems include: formaldehyde, methylene diphenyl diisocyanate (MDI), phenol, triethylamine, methanol, benzene, toluene, cresol/cresylic acid, napthalene, polycyclic-organics, and cyanide compounds (Twarog, 1993).

Some core-making processes use strongly acidic or basic substances for scrubbing the off gasses from the core making process. In the free radical cure process, acrylic-epoxy binders are cured using an organic hydroperoxide and SO_2 gas. Gasses are typically scrubbed to remove sulfur dioxide before release through the stack to the atmosphere. A wet scrubbing unit absorbs the SO_2 gas. A 5 to 10 percent solution of sodium hydroxide at a pH of 8 to 14 neutralizes the SO_2 and prevents the by-product (sodium sulfite) from precipitating out of solution (U.S. EPA, 1992).

Amine scrubbers may be used for sulfur dioxide control by foundries. In amine scrubbing the gas containing sulfur dioxide is first passed through a catalyst bed, where the sulfur compounds are converted to hydrogen sulfide. The gas stream then enters a packed or trayed tower (scrubber) where it is contacted with a solution of water and an organic amine. The amine solution is alkaline and the weakly acidic hydrogen sulfide in the gas stream dissolves in it. The amine solution with hydrogen sulfide is then sent to a stripping

tower, where it is boiled and the acid gases stripped out. The amine solution is cooled and returned to the scrubbing tower for reuse. Acid gases are cooled and treated through neutralization. A number of amines are used including diethanolamine (DEA), monoethanolamine (MEA), and methyldiethanolamine (MDEA). Air emissions from the amine scrubbers may include some H_2S and other sulfur compounds. (Scott, 1992).

Shakeout, Finishing, and Sand Handling
Shakeout and sand handling operations generate dust and metallic particulates. Finishing and cleaning operations will generate metallic particulates from deburring, grinding, sanding and brushing, and volatile organic compounds from the application of rust inhibitors or organic coatings such as paint. Control systems involve hoods and ducts at key dust generating points followed by baghouses, electrostatic precipitators, or wet scrubbers (AFS Air Quality Committee, 1992).

Wastewater

Wastewater mainly consists of noncontact cooling water and wet scrubber effluent (Leidel, 1995). Noncontact cooling water can typically be discharged to the POTW or to surface waters under an NPDES permit. Wet scrubber wastewater in facilities using large cupola furnaces can be generated in large quantities (up to 3,000 gallons per minute). This water is typically highly alkaline or acidic and is neutralized before being discharged to the POTW (AFS Air Quality Committee, 1992). If amine scrubbers are used, amine scrubbing solution can be released to the plant effluent system through leaks and spills. Some foundries using cupola furnaces also generate wastewater containing metals from cooling slag with water. Wastewater may also be generated in certain finishing operations such as quenching and deburring. Such wastewater can be high in oil and suspended solids (NADCA, 1996).

Residual Wastes

Residual wastes originate from many different points within foundries. Waste sand is by far the largest volume waste for the industry. Other residual wastes may include dust from dust collection systems, slag, spent investment casting refractory material, off-spec products, resins, spent solvents and cleaners, paints, and other miscellaneous wastes.

Furnaces and Metal Melting
The percentage of metal from each charge that is converted to dust or fumes and collected by baghouses, electrostatic precipitators, or wet scrubbers can vary significantly from facility to facility depending on the type of furnace used and the type of metal cast. In steel foundries, this dust contains varying amounts of zinc, lead, nickel, cadmium, and chromium. Carbon-steel dust

tends to be high in zinc as a result of the use of galvanized scrap, while stainless steel dust is high in nickel and chromium. Dust high in lead may result from the use of scrap painted with leaded paint. Dust associated with nonferrous metal production may contain copper, aluminum, lead, tin, and zinc. Steel dust may be encapsulated and disposed of in a permitted landfill, while nonferrous dust is often sent to a recycler for metal recovery.

Slag is a glassy mass with a complex chemical structure. It can constitute about 25 percent of a foundry's solid waste stream (Kotzin, 1995). Slag is composed of metal oxides from the melting process, melted refractories, sand, coke ash (if coke is used), and other materials. Large quantities of slag are generated in particular from iron foundries that melt in cupola furnaces. Fluxes are used to facilitate removal of contaminants from the molten metal into the slag so that it can be removed from the molten metal surface. Hazardous slag may be produced in melting operations if the charge materials contain toxic metals such as lead, cadmium, or chromium. To produce ductile iron by reducing the sulfur content of iron, some foundries use calcium carbide desulfurization and the slag generated by this process may be classified as a reactive waste (U.S. EPA, 1992).

Mold and Core Making

Those core-making processes that use strongly acidic or basic substances for scrubbing the off gasses from the core making process may generate sludges or liquors. These sludges or liquors are typically pH controlled prior to discharge to the sewer system as nonhazardous waste. If not properly treated, the waste may be classified as hazardous corrosive waste and thus subjected to numerous federal, state and local mandates (U.S. EPA, 1992).

Shakeout and Sand Handling

Foundries using sand molds and cores generate large volumes of waste sands. Waste foundry sand can account for 65 to 90 percent of the total waste generated by foundries. In many foundries, casting sands are recycled internally until they can no longer be used. Some foundries reclaim waste sands so that they can be recycled to the process or recycled off-site for another use (see Section V.A.1). Sand that can no longer be used by iron or steel foundries, is often landfilled as nonhazardous waste. Casting sands used in the production of brass or bronze castings may exhibit toxicity characteristic for lead or cadmium. The hazardous sand may be reclaimed in a thermal treatment unit which may be subject to RCRA requirements for hazardous waste incinerators (see Section VI.B) (U.S. EPA, 1992). Approximately two percent of all foundry spent sand is hazardous (Kotzin, 1995).

Investment casting shells can be used only once and are disposed in landfills as a nonhazardous waste unless condensates from heavy metal alloy constituents are present in the shells.

Most foundries generate miscellaneous residual waste that varies greatly in composition, but makes up only a small percentage of the total waste. This waste includes welding materials, waste oil from heavy equipment and hydraulics, empty binder drums, and scrubber lime (U.S. EPA, 1992).

III.B.2. Die Casters

The main raw material inputs for die casters include: metal in the form of ingot, molten metal, metal scrap, alloys, and fuel for metal melting. Other raw material inputs include: fluxing agents, die lubricants, refractory materials, hydraulic fluid, and finishing and cleaning materials.

Air Emissions

Furnace air emissions consist of the products of combustion from the fuel and particulate matter in the form of dusts, metallics, and metal oxide fumes. Carbon monoxide and oil vapors may also arise if oily scrap is charged to the furnace or preheat system. Metallic particulates arise mainly from the volatilization and condensation of molten metal oxides. These will vary according to the type of furnace, fuel, metal, melting temperature, and a number of operating practices. The particulate sizes of the oxide fumes are often very small (submicron) and may contain copper, aluminum, lead, tin, and zinc (Licht, 1992).

Fluxing and dross removal operations to remove impurities from the molten metal can also be the source of air emissions. Die casters can use a number of different fluxing agents to remove different impurities, including: sulfur hexafluoride, solvent fluxes, aluminum fluoride, or chlorine. Metallic particulates, the fluxing agents themselves, and products of chemical reactions with impurities can be emitted from the molten metal surface or from the subsequently removed dross as it cools. For example, if chlorine is used, it may react with aluminum and water in the atmosphere to form aluminum oxide fumes and hydrochloric acid. Although not always necessary, particulate emissions control equipment, such as fabric bag filters, are sometimes used to control furnace emissions at die casting facilities (NADCA, 1996).

Die lubrication and plunger tip lubrication can also be a significant source of air releases from die casting facilities. Both oil- and water-based die lubricants are used. Oil-based lubricants typically contain naphtha and result in much higher emissions of volatile organic compounds than water-based

lubricants. The air emissions will depend on the specific formulation of the lubricant product and may contain hazardous air pollutants (NADCA, 1996).

Other air emissions arise from finishing and cleaning operations which generate metallic particulates from deburring, grinding, sanding and brushing, and volatile organic compounds from the application of rust inhibitors or paint. Casting quench tanks for the cooling of zinc castings can contain volatile organic compounds and water treatment chemicals resulting in potential emissions of volatile organic compounds and hazardous air pollutants (NADCA, 1996).

Wastewater

Both process wastewater and waste noncontact cooling water may be generated at die casting facilities. Noncontact cooling water will likey have elevated temperature and very little or no chemical contamination. Process wastewater from die casting facilities can be contaminated with spent die lubricants, hydraulic fluid and coolants. Contaminants in such wastewater are typically oil and phenols. As with foundries, die casters may also generate wastewater in certain finishing operations such as in-process cleaning, quenching and deburring. Such wastewater can be high in oil and suspended solids. Typical wastewater treatment at die casting facilities consists of oil/water separation and/or filtration before discharge to a POTW. Facilities generating large volumes of wastewater may also utilize biological treatment (NADCA, 1996).

Residual Wastes

Residual waste streams from die casting facilities are relatively small compared to most sand casting foundries. Typical residual wastes include: slag or dross generated from molten metal surfaces; refractory materials from furnaces and ladles; metallic fines, spent shot (plunger) tips, tools, heating coils, hydraulic fluid, floor absorbent, abrasive cutting belts and wheels, quench sludge, and steel shot. Most residual wastes from die casting facilities are sent off-site for disposal as a non-hazardous waste. Waste dross is usually sent to secondary smelters for metal recovery. Waste oils, lubricants and hydraulic fluids may be sent off-site for recycling or energy recovery (NADCA, 1996).

Table 4: Summary of Material Inputs and Potential Pollutant Outputs for the Metal Casting Industry				
Industrial Process	**Material Inputs**	**Air Emissions**	**Wastewater**	**Residual Wastes**
Pattern Making	Wood, plastic, metal, wax, polystyrene	VOCs from glues, epoxies, and paints.	Little or no wastewater generated	Scrap pattern materials
Mold and Core Preparation and Pouring				
Green Sand	Green sand and chemically-bonded sand cores	Particulates, metal oxide fumes, carbon monoxide, organic compounds, hydrogen sulfide, sulfur dioxide, and nitrous oxide. Also, benzene, phenols, and other hazardous air pollutants (HAPs) if chemically bonded cores are used.	Wastewater containing metals, elevated temperature, phenols and other organics from wet dust collection systems and mold cooling water	Waste green sand and core sand potentially containing metals
Chemical Binding Systems	Sand and chemical binders	Particulates, metallic oxide fumes, carbon monoxide, ammonia, hydrogen sulfide, hydrogen cyanide, sulfur dioxide, nitrogen oxides, and other HAPs	Scrubber wastewater with amines or high or low pH; and wastewater containing metals, elevated temperature, phenols and other organics from wet dust collection systems and mold cooling water	Waste mold and core sand potentially containing metals and residual chemical binders
Permanent Mold	Steel mold, permanent, sand. plaster, or salt cores	Particulates, metallic oxide fumes	Waste cooling water with elevated temperature and wastewater with low pH and high in dissolved salts if soluble salt cores are used	Waste core sand or plaster potentially containing metals
Plaster Mold	Plaster mold material	Particulates, metallic oxide fumes	Little or no wastewater generated	Spent plaster
Investment/Lost Wax	Refractory slurry, and wax or plastic	Particulates, metallic oxide fumes	Wastewater with low pH and high in dissolved salts if soluble salt cores are used	Waste refractory material, waxes and plastics
Lost Foam	Refractory slurry, polystyrene	Particulates, metallic oxide fumes, polystyrene vapors and HAPs	Little or no wastewater generated	Waste sand and refractory material potentially containing metals and styrene

Industrial Process	Material Inputs	Air Emissions	Wastewater	Residual Wastes
Furnace Charge Preparation and Metal Melting				
Charging and Melting	Metal scrap, ingot and returned castings	Products of combustion, oil vapors, particulates, metallic oxide fumes	Scrubber wastewater with high pH, slag cooling water with metals, and non-contact cooling water	Spent refractory material potentially containing metals and alloys
Fluxing and Slag and Dross Removal	Fluxing agents	Particulates, metallic oxide fumes, solvents, hydrochloric acid	Wastewater containing metals if slag quench is utilized	Dross and slag potentially containing metals
Pouring	Ladles and other refractory materials	Particulates, metallic oxide fumes	Little or no wastewater generated	Spent ladles and refractory materials potentially containing metals
Quenching, Finishing, Cleaning and Coating				
Painting and rust inhibitor application	Paint and rust inhibitor	VOCs	Little or no wastewater generated	Spent containers and applicators
Cleaning , quenching, grinding, cutting	Unfinished castings, water, steel shot, solvents	VOCs, dust and metallic particulates	Waste cleaning and cooling water with elevated temperature, solvents, oil and grease, and suspended solids	Spent solvents, steel shot, metallic particulates, cutting wheels, metallic filings, dust from collection systems, and wastewater treatment sludge
Shakeout, Cooling and Sand Handling	Water and caustic for wet scrubbers	Dust and metallic particulates; VOC and organic compounds from thermal sand treatment systems	Wet scrubber wastewater with high or low pH or amines, permanent mold contact cooling water with elevated temperature, metals and mold coating	Waste foundry sand and dust from collection systems, metal
Die Casting[1]	Metal, fuel, lubricants, fluxing agents, hydraulic fluid	VOCs from die and plunger tip lubrication	Waste cooling water with elevated temperature and wastewater contaminated with oil, and phenols	Waste hydraulic fluid, lubricants, floor absorbent, and plunger tips

[1] Furnaces, metal melting, finishing, cleaning, and coating operations also apply to die casting.

III.C. Management of Chemicals in Wastestream

The Pollution Prevention Act of 1990 (PPA) requires facilities to report information about the management of Toxic Release Inventory (TRI) chemicals in waste and efforts made to eliminate or reduce those quantities. These data have been collected annually in Section 8 of the TRI reporting Form R beginning with the 1991 reporting year. The data summarized below cover the years 1993-1996 and are meant to provide a basic understanding of the quantities of waste handled by the industry, the methods typically used to manage this waste, and recent trends in these methods. TRI waste management data can be used to assess trends in source reduction within individual industries and facilities, and for specific TRI chemicals. This information could then be used as a tool in identifying opportunities for pollution prevention compliance assistance activities.

While the quantities reported for 1994 and 1995 are estimates of quantities already managed, the quantities listed by facilities for 1996 and 1997 are projections only. The PPA requires these projections to encourage facilities to consider future source reduction, not to establish any mandatory limits. Future-year estimates are not commitments that facilities reporting under TRI are required to meet.

Foundries

Table 5 shows that the TRI reporting foundries managed about 272 million pounds of production related wastes (total quantity of TRI chemicals in the waste from routine production operations in column B) in 1995. From the yearly data presented in column B, the total quantity of production related TRI wastes increased between 1994 and 1995. This is likely in part because the number of chemicals on the TRI list nearly doubled between those years. Production related wastes were projected to decrease in 1996 and 1997. The effects of production increases and decreases on the amount of wastes generated are not evaluated here.

Values in Column C are intended to reveal the percent of production-related waste (about 40 percent) either transferred off-site or released to the environment. Column C is calculated by dividing the total TRI transfers and releases by the total quantity of production-related waste. Column C shows a decrease in the amount of wastes either transferred off-site or released to the environment from 43 percent in 1994 to 40 percent in 1995. In other words, about 60 percent of the industry's TRI wastes were managed on-site through recycling, energy recovery, or treatment as shown in columns D, E, and F, respectively. Most of these on-site managed wastes were recycled on-site, typically in a metals recovery process. The majority of waste that is released or transferred off-site can be divided into portions that are recycled off-site,

recovered for energy off-site, or treated off-site as shown in columns G, H, and I, respectively. The remaining portion of the production related wastes (32 percent in 1994 and 1995), shown in column J, is either released to the environment through direct discharges to air, land, water, and underground injection, or is transferred off-site for disposal.

Table 5: Source Reduction and Recycling Activity for Foundries (SIC 332, 3365, 3366, and 3369) as Reported within TRI									
A	**B**	**C**	**On-Site**			**Off-Site**			**J**
Year	Quantity of Production-Related Waste (10⁶ lbs.)ᵃ	% Released and Transferredᵇ	**D** % Recycled	**E** % Energy Recovery	**F** % Treated	**G** % Recycled	**H** % Energy Recovery	**I** % Treated	% Released and Disposedᶜ Off-site
1994	232	43%	58%	0%	1%	18%	0%	0%	32%
1995	272	40%	58%	0%	2%	16%	0%	1%	32%
1996	264	---	54%	0%	2%	20%	0%	1%	24%
1997	261	---	53%	0%	2%	21%	0%	1%	24%

Source: *1995 Toxics Release Inventory Database.*

ᵃ Within this industry sector, non-production related waste < 1% of production related wastes for 1995.

ᵇ Total TRI transfers and releases as reported in Section 5 and 6 of Form R as a percentage of production related wastes.

ᶜ Percentage of production related waste released to the environment and transferred off-site for disposal.

Die Casters

Table 6 shows that the TRI reporting foundries managed about 63 million pounds of production related wastes (total quantity of TRI chemicals in the waste from routine production operations) in 1995 (column B). Column C reveals that of this production-related waste, about 21 percent was either transferred off-site or released to the environment. Column C is calculated by dividing the total TRI transfers and releases by the total quantity of production-related waste. In other words, about 79% of the industry's TRI wastes were managed on-site through recycling, energy recovery, or treatment as shown in columns D, E, and F, respectively. Most of these on-site managed wastes were recycled on-site, typically in a metals recovery process. The majority of waste that is released or transferred off-site can be divided into portions that are recycled off-site, recovered for energy off-site, or treated off-site as shown in columns G, H, and I, respectively. The remaining portion of the production related wastes (2 percent in 1994), shown in column J, is either released to the environment through direct discharges to air, land, water, and underground injection, or it is disposed off-site.

A	B	C	On-Site			Off-Site			J
Year	Quantity of Production-Related Waste (10^6 lbs.)[a]	% Released and Transferred[b]	D % Recycled	E % Energy Recovery	F % Treated	G % Recycled	H % Energy Recovery	I % Treated	% Released and Disposed[c] Off-site
1994	60	23%	69%	0%	3%	27%	0%	0%	2%
1995	63	21%	75%	0%	3%	21%	0%	0%	2%
1996	64	---	75%	0%	3%	21%	0%	0%	1%
1997	64	---	76%	0%	2%	21%	0%	0%	1%

Table 6: Source Reduction and Recycling Activity for Die Casting Facilities (SIC 3363 and 3364) as Reported within TRI

Source: *1995 Toxics Release Inventory Database.*

[a] Within this industry sector, non-production related waste < 1% of production related wastes for 1995.

[b] Total TRI transfers and releases as reported in Section 5 and 6 of Form R as a percentage of production related wastes.

[c] Percentage of production related waste released to the environment and transferred off-site for disposal.

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